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Conventional and High-Strength Headed Bars—Part 2: Data Analysis

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Equations to characterize the anchorage strength of headed bars were developed, incorporating key factors affecting anchorage strength: concrete compressive strength; embedment length; bar diameter; spacing between the bars; and confining reinforcement parallel to the headed bars. Results from tests of 138 exterior beam-column joints, 64 without and 74 with confining reinforcement within the joint region, were used to develop the equations. Concrete compressive strengths ranged from 4050 to 16,030 psi (27.9 to 110.6 MPa) and bar stresses at failure ranged from 33,100 to 153,160 psi (228 to 1056 MPa). The bearing area of the headed bars ranged from 3.8 to 9.5 times the area of the bar. Some headed bars contained obstructions adjacent to the head that exceeded the dimensions permitted for HA heads in ACI 318-14 and ASTM A970-13a but are now permitted by ASTM A970-18. The test results show that headed bar anchorage strength is proportional to the concrete compressive strength raised to the power 0.24. The contribution of confining reinforcement is proportional to the area of confining reinforcement parallel to the headed bar within eight to 10 bar diameters of the headed bar. Headed bars with obstructions larger than those permitted in ACI 318-14 that meet the provisions in ASTM A970-18 exhibit anchorage strengths that are similar to those that meet the provisions in ACI 318-14.

Keywords: anchorage; beam-column joints; bond and development; headed bars; high-strength concrete, high-strength steel; reinforcement.

INTRODUCTION

Headed bars are often used to anchor reinforcing steel as a means of reducing congestion where member geometry precludes adequate anchorage with a straight bar. Prior to the current study (Shao et al. 2016; Ghimire et al. 2018, 2019), only limited results were available on the behavior of headed bars, with no data on high-strength headed bars or applications dealing with high-strength concrete. The design provisions in ACI 318, which first appeared in ACI 318-08, are based on the analysis of a small number of test specimens with a limited range of concrete compressive strengths and bar stresses at failure (DeVries et al. 1998, 1999; Thompson et al. 2005, 2006a,b). None of the tests involved beam-column joints. Due to the lack of experimental information, the design provisions for development length of headed reinforcing bars in ACI 318-14 limit the yield strength of headed reinforcing steel to 60,000 psi (420 MPa) and the concrete compressive strength for calculating development length to 6000 psi (40 MPa). ACI 318-14 also requires the clear spacing between the bars to be at least four times the bar diameter and does not account for the contribution of confining reinforcement to anchorage strength. These limits restrict the use of headed bars and prevent the full benefits of higher-strength reinforcing steel and concrete from being realized. The purpose of this study is to identify the primary factors that affect the anchorage strength of the headed bars and develop an expression that characterizes the anchorage strength of the headed bars that incorporates the key parameters and is applicable to the full range of concrete and steel strengths used in construction. The study includes an evaluation of headed bars with obstructions that exceed the dimensions permitted by ACI 318-14.

The equation for the development length of headed bars in tension, ℓ_{dt} (in. or mm) in Section 25.4.4.2 of ACI 318-14, is

$$\ell_{dt} = \left(\frac{0.016 f_y \psi_e}{\sqrt{f_c'}} \right) d_b \text{ (in.-lb)} \tag{1a}$$

$$\ell_{dt} = \left(\frac{0.19 f_y \psi_e}{\sqrt{f_c'}} \right) d_b \text{ (SI)} \tag{1b}$$

where f_y is the yield strength of the bar (psi or MPa), with an upper limit of 60,000 psi (420 MPa); f_c' is the compressive strength of concrete (psi or MPa), with an upper limit of 6000 psi (40 MPa); d_b is the bar diameter (in. or mm); and ψ_e the is modification factor for epoxy-coated or zinc and epoxy dual-coated bars. The development length ℓ_{dt} may be no less than the larger of $8d_b$ or 6 in. (150 mm).

To enable comparison of Eq. (1) with test results, the equation is solved for the stress in the headed bar, replacing ℓ_{dt} with ℓ_{eh}, corresponding to the actual embedment length (measured from the critical section to the bearing face of the head). f_y is replaced by $f_{s,ACI}$, and f_c' is replaced by f_{cm}, giving

$$f_{s,ACI} = \frac{\ell_{eh} \sqrt{f_{cm}}}{0.016 d_b \psi_e} \text{ (in.-lb)} \tag{2a}$$

$$f_{s,ACI} = \frac{\ell_{eh} \sqrt{f_{cm}}}{0.19 d_b \psi_e} \text{ (SI)} \tag{2b}$$

For a given embedment length, Eq. (2) indicates that the stress developed in a headed bar corresponding to an anchorage failure is proportional to the square root of

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concrete compressive strength and inversely proportional to the bar diameter. As demonstrated by Shao et al. (2016) and Ghimire et al. (2019), however, the square root of concrete compressive strength overestimates the increase in stress in the bar as the compressive strength increases, and the stress drops more rapidly with increased bar size than characterized by the inverse of the bar diameter. Specifically, Eq. (2) is very conservative in predicting the anchorage strength of headed No. 5 (No. 16) bars but becomes progressively less conservative with increasing bar size and concrete compressive strength.

These observations demonstrate that the current provisions (ACI 318-14) for the development length of headed bars are not applicable over the full range of concrete compressive strengths and bar sizes used in practice. To address these inconsistencies and incorporate key factors affecting the anchorage strength of headed bars including concrete compressive strength, embedment length, bar diameter, spacing between the bars, and confining reinforcement, descriptive equations are developed that accurately characterize the anchorage strength of the headed bars.

RESEARCH SIGNIFICANCE

Expressions that characterize the anchorage strength of headed bars in concrete are scarce in the literature. Those that are available are either too specific to the tests from which they were developed or do not address the full range of factors affecting anchorage strength. This paper aims to develop descriptive equations for the anchorage strength of headed bars that are applicable over the full range of concrete and steel strengths currently used in construction, along with the other key factors that control anchorage strength.

HEADED BAR DATABASE

As part of a comprehensive study on the anchorage behavior of headed bars (Shao et al. 2016; Ghimire et al. 2018, 2019), 202 exterior beam-column joint specimens were tested under monotonic loading. The key parameters studied were concrete compressive strength, bar size, embedment length, head size, spacing between the bars, and confining reinforcement within the joint region. Results from 138 out of the 202 specimens, 64 without and 74 with confining reinforcement within the joint region, were used to develop descriptive equations for the anchorage strength of the headed bars. Specimens that provided a wide range of the key parameters affecting the anchorage strength of headed bars were selected. Headed bars without and with confining reinforcement within the joint region were considered. Specimens with bars containing heads with net bearing areas of 3.8 to $9.5A_b$ (A_b is nominal bar area) and side cover of 2.5 to 4 in. (65 to 100 mm) were selected as the data set used to develop the descriptive equations. Specimens with large heads (12.9 to $14.9A_b$) were not included in the development of the equations because, as described by Ghimire et al. (2019), the bars with large heads exhibited higher anchorage strengths than bars with $9.5A_b$ and smaller heads. Some headed bars with short embedment lengths ℓ_{eh} relative to the distance from the center of the bar to the top of bearing member tended to exhibit low anchorage strengths and were not used to develop the descriptive equations. As demonstrated by Shao et al. (2016), it is more appropriate to evaluate the latter specimens using strut-and-tie models (ACI 318-14). Two specimens in an early test group had no confining reinforcement above or within the joint region and served as trial specimens to provide information for the design of subsequent beam-column joint specimens. Because the lack of confining reinforcement above the joint is inconsistent with design requirements for reinforced concrete columns (ACI 318-14), these specimens were also not used to develop the descriptive equations. The specimens used in the analysis are listed in Table A.2 of Appendix A.* Specimen details are presented in Table A.3 of Appendix A. The measured concrete compressive strengths f_{cm} ranged from 4050 to 16,030 psi (27.9 to 110.6 MPa). No. 5, No. 8, and No. 11 (No. 16, No. 25, and No. 36) headed bars with embedment lengths ℓ_{eh} ranging from 3.75 to 19.75 in. (95 to 502 mm) were tested. Center-to-center spacing between the headed bars, c_{ch}, ranged from 2.9 to 11.8 bar diameters d_b. Friction-forged, taper-threaded, and cold-swaged heads, representing a variety of manufacturing processes, were evaluated. Some cold-swaged headed bars included in the analysis contained a threaded coupling sleeve adjacent to the bearing face of the head that exceeded the size of obstructions permitted for HA heads in accordance with ACI 318-14 and ASTM A970-13a. As demonstrated by Shao et al. (2016) and later in this paper, these headed bars exhibited anchorage strengths that were similar to those meeting the provisions in ACI 318-14 and were, thus, included in the data used to develop the equations. Details of the heads are provided in Appendix A and by Ghimire et al. (2018, 2019). Three levels of confining reinforcement placed parallel to the bar within the joint region were studied: no confining reinforcement; two No. 3 hoops; and No. 3 hoops spaced at $3d_b$ (meeting the requirements for a 0.8 reduction factor for the development length calculation of 90-degree hooked bars in accordance with ACI 318-14, allowing comparisons to be made between hooked and headed bars for a constant amount of joint reinforcement). Bar stresses at failure ranged from 33,100 to 153,160 psi (228 to 1056 MPa). The loading configuration for the beam-column joint specimens is shown in Fig. 1. The headed bars in tension represent the top reinforcement in a beam subjected to negative bending, and the bearing member simulates the compression region of the beam.

ANALYSIS OF TEST RESULTS

To develop equations that characterize the behavior of headed bars without and with confining reinforcement in simulated beam-column joints, a series of iterative statistical analyses were performed. A least-squares regression technique involving dummy variables was used to determine the effects of key design parameters on the anchorage strength (Draper and Smith 1981). This technique results in a series of parallel lines with different intercepts (Fig. 2) that represent trends in the data. The legends in the figure reflect the order

*The Appendix is available at **www.concrete.org/publications** in PDF format, appended to the online version of the published paper. It is also available in hard copy from ACI headquarters for a fee equal to the cost of reproduction plus handling at the time of the request.

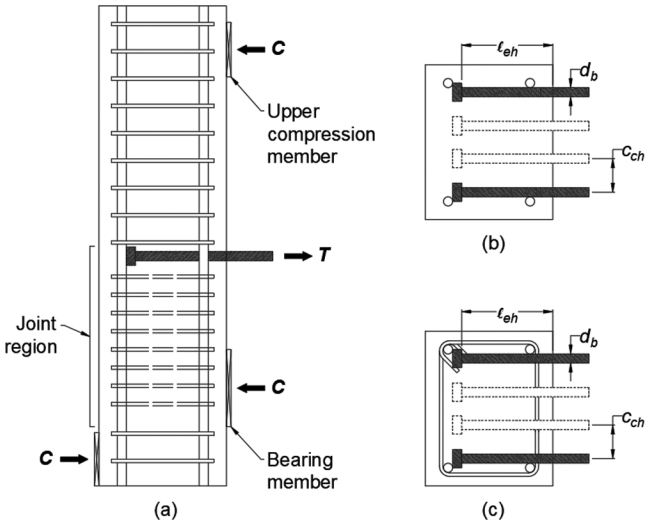

Fig. 1—Beam-column joint specimens: (a) side view with loading configuration; (b) cross section of specimen at joint region without confining reinforcement; and (c) cross section of specimen at joint region with confining reinforcement parallel to headed bar.

of the data subsets from top to bottom. Descriptive equations of the anchorage strength of headed bars were developed using iterative non-linear regression analyses to ensure a mean test-to-calculated ratio equal to 1.0 while minimizing the sum of the squared differences (1-Test/Calculated)^2.

Descriptive equations for headed bars without confining reinforcement

Widely spaced bars—The descriptive equation for the anchorage strength of headed bars without confining reinforcement is based on test results of the 30 specimens with widely spaced bars (center-to-center spacing $\geq 8d_b$) and is given by

$$T_c = 781 f_{cm}^{0.25} \ell_{eh}^{1.03} d_b^{0.35} \text{ (in.-lb)} \quad (3a)$$

$$T_c = 132 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35} \text{ (SI)} \quad (3b)$$

where T_c is the anchorage strength of headed bars without confining reinforcement (lb or N); f_{cm} is the concrete compressive strength (psi or MPa); ℓ_{eh} is the embedment length (in. or mm); and d_b is the diameter of the headed bar (in. or mm).

Figure 2 compares the ratio of test-to-calculated failure load T/T_c with the concrete compressive strength for the 30 specimens. T is the average bar force at failure calculated at the peak load on the specimen divided by number of headed bars. In Fig. 2, the dummy variable lines are almost horizontal, indicating that Eq. (3) provides a good match with the test results for concrete strengths between approximately 4000 and 16,000 psi (27.6 and 110 MPa). The values of T/T_c range from 0.80 to 1.18, with a mean, standard deviation, and coefficient of variation of 1.00, 0.100, and 0.100, respectively.

Equation (3) and Fig. 2 indicate that the anchorage strength of widely spaced headed bars is proportional to the concrete compressive strength to the 0.24 power, rather than

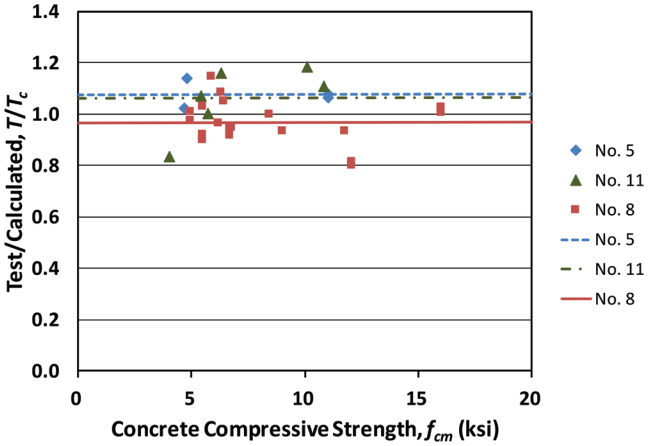

Fig. 2—Ratio of test-to-calculated failure load T/T_c *versus measured concrete compressive strength* f_{cm} *for specimens with widely spaced bars and no confining reinforcement. (Note: 1 psi = 0.006895 MPa.)*

the 0.5 power of compressive strength, as traditionally used in the ACI Code (ACI 318-14). This observation is consistent with the findings by Darwin et al. (1996, 2005) and Zuo and Darwin (1998, 2000) on the splice strength of straight bars and by Sperry et al. (2015a,b; 2017) on the anchorage strength of hooked bars, indicating that concrete compressive strength to a power close to 1/4 provides a superior representation of behavior. Justification for the lower power of compressive strength is provided by the fact that both the bond strength of straight reinforcement and the anchorage strength of hooked and headed bars are governed by the combined effects of concrete tensile strength, which controls initial crack formation and increases with the compressive strength to a power between 1/2 and 2/3, and fracture energy, which controls crack propagation and is independent of compressive strength (Darwin et al. 2001). The overall effect is a power between 0.5 and zero.

Equation (3) also indicates that the anchorage strength of headed bars increases almost linearly with the embedment length and that for the same concrete strength and embedment length, larger bars exhibit higher anchorage strengths. The higher strength of larger bars is likely due, at least in part, to the greater effectiveness of the larger heads associated with larger-size bars. The observation that larger headed bars have higher anchorage strengths is also consistent with the observations that larger bars have higher splice strengths than smaller bars for the same splice length (Darwin et al. 1996, 2005; Zuo and Darwin 1998, 2000; Darwin 2005), and larger hooked bars have higher anchorage strengths than smaller hooked bars for the same embedment length (Sperry et al. 2015a,b; 2017).

Closely spaced bars—For the 34 specimens with closely spaced bars (center-to-center spacing $< 8d_b$), the ratios of anchorage strengths T/T_c (T_c based on Eq. (3)) are plotted versus the center-to-center spacing between the bars in Fig. 3. For comparison, the 30 specimens with widely spaced bars used to develop Eq. (3) are also shown in the figure, represented by open symbols.

As shown in Fig. 3, the anchorage strengths of the closely spaced headed bars, regardless of bar size, were generally

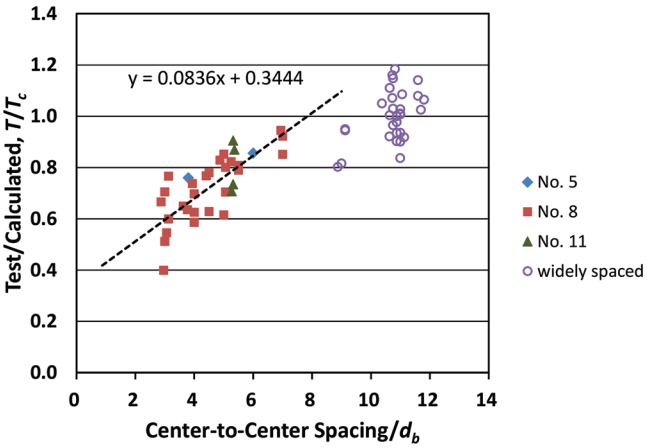

Fig. 3—Ratio of test-to-calculated failure load T/T_c *versus center-to-center spacing for headed bars without confining reinforcement.*

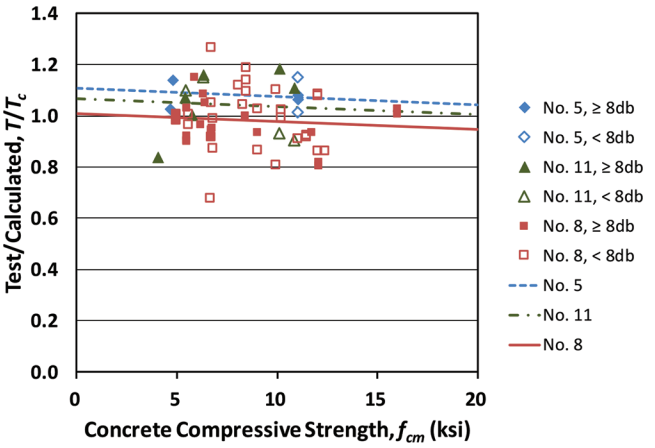

Fig. 4—Ratio of test-to-calculated failure load T/T_c *versus measured concrete compressive strength* f_{cm} *for specimens without confining reinforcement. (Note: 1 psi = 0.006895 MPa.)*

weaker than those of the widely spaced bars. The trend line for the closely spaced bars shows an increase in anchorage strength with an increase in bar spacing. The value of T/T_c equals 1.0 at a center-to-center spacing of approximately $8d_b$, which is greater than the value of $6d_b$ observed for closely spaced hooked bars tested in simulated beam-column joint specimens by Ajaam et al. (2017, 2018). The difference in critical bar spacing between headed and hooked bars is likely due to the geometry of the head; the larger size of the head relative to the bar reduces the effective clear spacing between heads and may result in interaction between headed bars at slightly greater spacings than was observed for hooked bars. Modifying Eq. (3) to account for the effect of closely spaced headed bars results in Eq. (4)

$$T_c = (781 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35}) \left(0.0836 \frac{c_{ch}}{d_b} + 0.3444 \right) \text{(in.-lb)} \quad (4a)$$

with $0.0836(c_{ch}/d_b) + 0.3444 \le 1.0$

$$T_c = (132 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35}) \left(0.0836 \frac{c_{ch}}{d_b} + 0.3444 \right) \text{(SI)} \quad (4b)$$

with $0.0836(c_{ch}/d_b) + 0.3444 \le 1.0$

where c_{ch} is the center-to-center spacing between the bars (in. or mm).

Figure 4 compares the ratio T/T_c to the concrete compressive strength for the headed bars (both widely spaced and closely spaced) without confining reinforcement, with T_c based on Eq. (4). The slope of the dummy variable lines in the figure indicates that the effect of concrete compressive strength is slightly overestimated by Eq. (4). A slightly lower value for the power of f_{cm} might be more suitable for the combined widely spaced and closely spaced bars, but for simplicity, the 0.24 power for f_{cm} is retained. The ratio T/T_c ranges from 0.68 to 1.27, with a mean, standard deviation, and coefficient of variation of 1.00, 0.111, and 0.111.

With the descriptive equations (Eq. (3) and (4)) developed for headed bars without confining reinforcement, the ratios of test-to-calculated failure load T/T_c are plotted versus

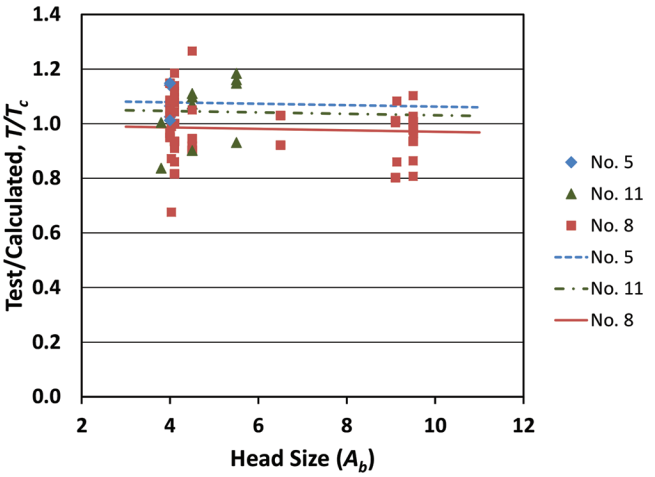

Fig. 5—Ratio of test-to-calculated failure load T/T_c *versus head size for specimens without confining reinforcement.*

head size (net bearing area with respect to bar area) in Fig. 5 for the specimens used to develop the descriptive equations. The slightly negative slope of the trend lines shown in Fig. 5, primarily based on the range of head sizes for No. 8 bars, indicates that the anchorage strength for headed bars without confining reinforcement has a minimal correlation with the head size for heads with bearing areas between 3.8 and $9.5A_b$. This, in turn, justifies grouping headed bars with bearing areas from 3.8 to $9.5A_b$ as a single series for the development of the descriptive equations.

Although not covered in this paper, an analysis of a wider range of specimen types indicates that a modification factor of 0.8 should be applied to T_c or T_h for headed bars terminating inside a column core (a region of the column cross section located inside the column longitudinal reinforcement) with a clear cover to the bar less than 2.5 in. (64 mm), or terminating in a member other than beam-column joints with clear side cover to the bar less than $8d_b$ (Shao et al. 2016).

Descriptive equations for headed bars with confining reinforcement

Widely spaced bars—For the 43 specimens with widely spaced bars and confining reinforcement within the joint region, the development of a descriptive equation is based on two assumptions: 1) the anchorage strength (T_h) is the sum of a concrete contribution T_c, given by Eq. (3), and a contribution from the confining reinforcement within the joint region T_s; and 2) the contribution from confining reinforcement is directly related to an effective quantity of confining reinforcement. Confining reinforcement is considered effective if it is fully anchored, in the form of closed hoops, and is located close to the top of the headed bar—within $8d_b$ for No. 3 through No. 8 bars and within $10d_b$ for No. 9 through No. 11 bars. These regions match those observed for hooked bars anchored in simulated beam-column joints (Sperry et al. 2015a,b, 2017).

The second assumption (dealing with the location of the effective confining reinforcement) is supported by the strain measurements in the confining reinforcement (Shao et al. 2016; Ghimire et al. 2018). The results indicate that the hoops located within the appropriate region ($8d_b$ or $10d_b$) experienced a significant strain increase at failure (almost all yielded), while the hoops outside this region exhibited much less or a negligible increase in strain. This assumption is also supported by observations of specimens after failure. Most cracks at failure were confined by the hoops that were close to the headed bars, rather than by all the hoops provided in the joint region. Figure 6 shows cracks for a specimen with No. 3 hoops spaced at $3d_b$. The photo was taken after the loose concrete had been removed from the specimen following failure. The specimen contained six hoops within the joint region, but only the top four hoops crossed the major diagonal crack that propagated from the bottom of the head toward the bearing member. The bottom two hoops—one slightly above the top of the bearing member and another slightly below the top of the bearing member (within the compression region)—were below the cracked region.

Based on these assumptions and the analysis of the 43 specimens with confining reinforcement, the contribution of confining reinforcement can be expressed as

$$T_s = 48{,}800\frac{A_{tt}}{n}d_b^{0.88}\ \text{(in.-lb)} \tag{5a}$$

$$T_s = 19.5\frac{A_{tt}}{n}d_b^{0.88}\ \text{(SI)} \tag{5b}$$

where T_s is the contribution of confining reinforcement to the anchorage strength of a headed bar (lb or N); A_{tt} is the total cross-sectional area of effective confining reinforcement parallel to the headed bars being developed (in.^{2} or mm^2), which is the product of the cross-sectional area of a single leg of confining reinforcement ($A_{tr;l}$) and the total number of single legs of confining reinforcement parallel to the straight portion of a headed bar within $8d_b$ from top of headed bar for No. 3 through No. 8 (No. 10 through No. 25) headed bars and within $10d_b$ from top of headed bar for No. 9 through

Fig. 6—Cracks confined by effective confining reinforcement (Specimen 11-5-F3.8-6#3-i-2.5-3-12).

No. 11 (No. 29 through No. 36) headed bars (N); n is the number of headed bars; and d_b is the diameter of headed bar (in. or mm). The term A_{tt}/n is the area of confining reinforcement per headed bar with an upper limit of $0.3A_b$.

Equation (5) indicates that the anchorage strength of headed bars is proportional to the amount of confining reinforcement parallel to the bar and to the bar diameter to the power 0.88. The fact that d_b appears in the equation indicates that a given quantity of confining reinforcement is more effective in increasing the anchorage forces as the size of the headed bar increases. These observations are, in general, consistent with the contribution of confining reinforcement parallel to hooked bars as expressed in Eq. (6) (Sperry et al. 2017). The power of 1.06 on the confining reinforcement term A_{th}/n is close to 1.0, signifying a linear relationship between the anchorage strength of hooked bars (T_s) and confining reinforcement

$$T_s = 54{,}250\left(\frac{A_{th}}{n}\right)^{1.06}d_b^{0.59}\ \text{(in.-lb)} \tag{6a}$$

$$T_s = 37.6\left(\frac{A_{th}}{n}\right)^{1.06}d_b^{0.59}\ \text{(SI)} \tag{6b}$$

where A_{th} is the total cross-sectional area of effective confining reinforcement parallel to the hooked bars being developed (in.^{2} or mm^2), analogous to A_{tt} for headed bars.

Combining Eq. (3) with Eq. (5), the anchorage strength for widely spaced headed bars with confining reinforcement can be expressed as

$$T_h = 781f_{cm}^{0.24}\ell_{eh}^{1.03}d_b^{0.35} + 48{,}800\frac{A_{tt}}{n}d_b^{0.88}\ \text{(in.-lb)} \tag{7a}$$

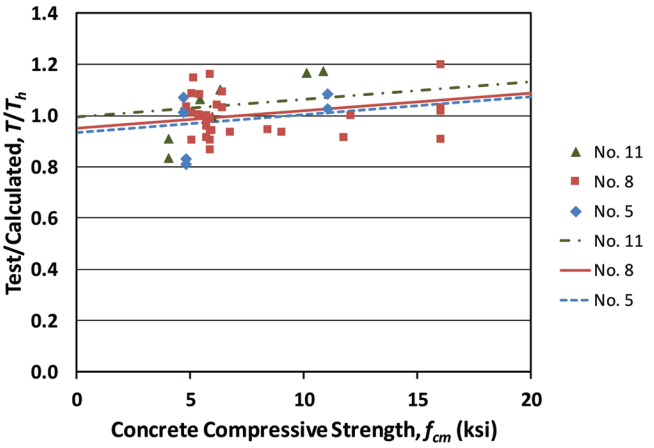

Fig. 7—Ratio of test-to-calculated failure load T/T_h *versus measured concrete compressive strength* f_{cm} *for specimens with widely-spaced bars and confining reinforcement. (Note: 1 psi = 0.006895 MPa.)*

$$T_h = 132.1 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35} + 19.5 \frac{A_{tt}}{n} d_b^{0.88} \text{ (SI)} \quad (7b)$$

Figure 7 compares the ratio T/T_h to the concrete compressive strength f_{cm} for the 43 specimens. T is the average peak load. T_h is based on Eq. (7). The slope of dummy variable lines in the figure indicates that the effect of concrete compressive strength is slightly underestimated by Eq. (7). The values of T/T_h range from 0.81 to 1.20, with a mean, standard deviation, and coefficient of variation of 1.00, 0.095, and 0.095, respectively.

Closely spaced bars—For the 31 specimens with closely spaced bars and confining reinforcement, the ratios of anchorage strengths T/T_h, with T_h based on Eq. (7), are plotted versus the center-to-center spacing between the bars in Fig. 8. The 43 specimens with widely spaced headed bars used to develop Eq. (7) are also shown in the figure, represented by open symbols.

Like the closely spaced headed bars without confining reinforcement, Fig. 8 shows that the closely spaced bars with confining reinforcement generally exhibited lower anchorage strengths than the widely spaced bars. The trend line, however, is flatter than that shown in Fig. 3, indicating that the anchorage strength of headed bars with confining reinforcement is affected less by close bar spacing than that of headed bars without confining reinforcement. Of the 31 specimens with closely spaced bars and confining reinforcement, 14 had two No. 3 hoops and 17 had No. 3 hoops at $3d_b$. Based on the trend line shown in Fig. 8, the anchorage strength for both closely and widely spaced headed bars with confining reinforcement can be expressed as

$$T_h = \left(781 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35} + 48{,}800 \frac{A_{tt}}{n} d_b^{0.88}\right)\left(0.0622 \frac{c_{ch}}{d_b} + 0.5428\right) \text{ (in.-lb)} \quad (8a)$$

$$T_h = \left(132 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35} + 19.5 \frac{A_{tt}}{n} d_b^{0.88}\right)\left(0.0622 \frac{c_{ch}}{d_b} + 0.5428\right) \text{ (SI)} \quad (8b)$$

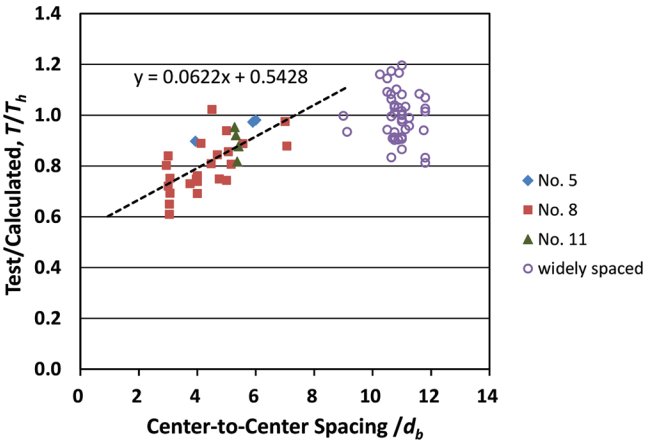

Fig. 8—Ratio of test-to-calculated failure load T/T_h *versus center-to-center spacing for headed bars with confining reinforcement.*

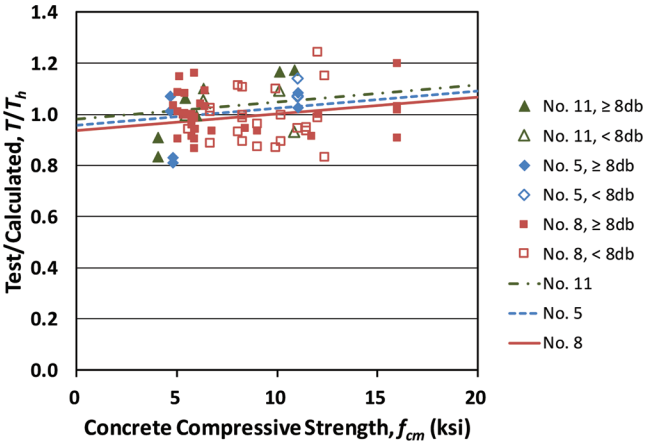

Fig. 9—Ratio of test-to-calculated load T/T_h *versus measured concrete compressive strength* f_{cm} *for specimens with confining reinforcement. (Note: 1 psi = 0.006895 MPa.)*

with $0.0622(c_{ch}/d_b) + 0.5428 \le 1.0$ and $A_{tt}/n \le 0.3A_b$.

Figure 9 compares the ratio T/T_h with concrete compressive strength for the headed bars (both widely spaced and closely spaced) with confining reinforcement, with T_h based on Eq. (8). The slope of dummy variable lines in the figure indicates that the effect of concrete compressive strength is slightly underestimated by Eq. (8). The ratio T/T_h ranges from 0.81 to 1.24, with a mean, standard deviation, and coefficient of variation of 1.00, 0.095, and 0.095, respectively.

With the descriptive equation (Eq. (8)) developed for headed bars with confining reinforcement, the ratios of test-to-calculated failure load T/T_h are plotted versus head size in Fig. 10 for the specimens used to develop the descriptive equations.

The closely spaced, slightly upward trend lines shown in Fig. 10 indicate that within a range of 3.8 to $9.5A_b$, head size has a minimal influence on the anchorage strength for headed bars with confining reinforcement. As was found for specimens without confining reinforcement, this result justifies treating headed bars with 3.8 to $9.5A_b$ heads as a single series for the development of the descriptive equations.

In Fig. 11, the failure loads T for all specimens are compared with the values of calculated failure load T_h

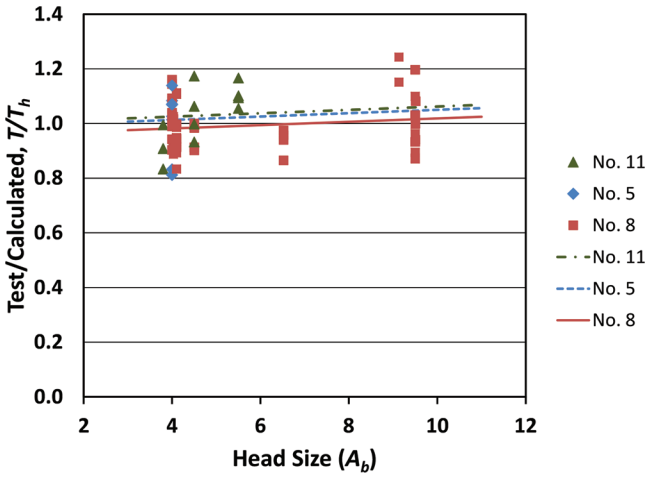

Fig. 10—Ratio of test-to-calculated failure load T/T_h *versus head size for specimens with confining reinforcement.*

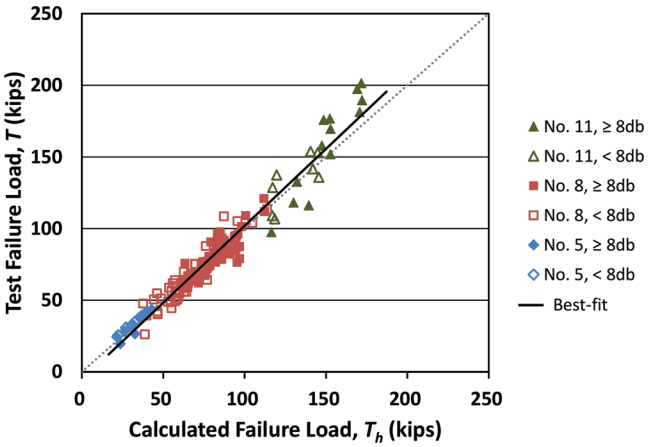

Fig. 11—Test failure load T *versus calculated failure load* T_h *for specimens without and with confining reinforcement.* T_h *is calculated based on Eq. (4) and (8). (Note: 1 kip = 4.448 kN.)*

obtained using the descriptive equations, Eq. (4) and (8). As shown in the figure, the descriptive equations slightly overestimate the anchorage strength for No. 5 bars and slightly underestimate the anchorage strength for No. 11 bars. The variation, however, is small given the range of data.

Headed bars with large obstructions

The anchorage strengths of headed bars with cold-swaged threaded coupling sleeves with obstructions exceeding the dimensional limits for HA heads in ASTM A970-13a (heads permitted by ACI 318-14) O4.5 and O9.1, were compared with the anchorage strengths of the headed bars meeting the requirements. The net bearing area of the large obstruction heads is taken as the difference between the gross area of head and the area of the obstruction adjacent to the head. The dimensions of the heads and obstructions are shown in Appendix A. Twenty-two specimens contained headed bars with large obstructions with net bearing areas of 4.5 and 9.1A_b. Of the 22 specimens, 14 had no confining reinforcement and eight had confining reinforcement within the joint region parallel to the headed bar. For the 14 specimens without confining reinforcement, the ratio of test-to-calculated failure load T/T_c ranged from 0.90 to 1.27, with a mean, standard deviation, and coefficient of variation of 1.01, 0.107, and 0.106, respectively. For the remaining eight specimens with confining reinforcement, the ratio of test-to-calculated failure load T/T_h ranged from 0.90 to 1.17, with a mean, standard deviation, and coefficient of variation of 0.99, 0.089, and 0.090, respectively. This indicates that the headed bars with large obstructions have similar anchorage strengths to those that met the requirements of HA heads in ASTM A970-13a and can be safely used in design. These observations were used to modify the criteria for the size of obstructions and are now permitted for HA heads by ASTM A970-18.

SUMMARY AND CONCLUSIONS

Descriptive equations for the anchorage strength of headed bars in concrete were developed. The descriptive equations account for the effects of concrete compressive strength, embedment length, bar size, spacing between the bars, and confining reinforcement. Results from 138 beam-column joint specimens, 64 without and 74 with confining reinforcement within the joint region, were used to develop the equations. No. 5, No. 8, and No. 11 (No. 16, No. 25, and No. 36) headed bars with embedment lengths ranging from 3.75 to 19.75 in. (95 to 502 mm) were tested in concrete compressive strengths ranging from 4050 to 16,030 psi (27.9 to 110.6 MPa). Center-to-center spacing between the headed bars ranged from 2.9 to 11.8 bar diameters. Bar stresses at failure ranged from 33,100 to 153,160 psi (228 to 1056 MPa). Some headed bars contained obstructions adjacent to the head that exceeded the dimensions permitted for HA heads in ACI 318-14 and ASTM A970-13a but are now permitted by ASTM A970-18.

The following conclusions are drawn based on the results presented in this paper.

1. The effect of concrete compressive strength on the anchorage strength of headed bars can be represented by the compressive strength to the 0.24 power, which is close to the relationship for the development length of straight bars and the anchorage strength of hooked bars.

2. Anchorage strength is improved by the addition of confining reinforcement parallel to the headed bar, a factor that is not included in current design provisions; the increase in anchorage strength is proportional to the amount of confining reinforcement per headed bar within eight to 10 bar diameters of the headed bar.

3. For a given embedment length, the anchorage strength of headed bars increases with an increase in bar diameter.

4. The anchorage strength of headed bars begins to decrease as the center-to-center spacing between the bars decreases below eight bar diameters, another factor not included in current design provisions.

5. Headed bars with obstructions larger than permitted in ACI 318-14 and ASTM A970-13a that meet the new provisions in ASTM A970-18 exhibit similar anchorage strengths to those that meet the provisions in ACI 318-14.

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NOTATION

A_{brg}	=	net bearing area of head
A_{th}	=	total cross-sectional area of effective confining reinforcement within joint region for hooked bars
$A_{tr,l}$	=	cross-sectional area of single leg of confining reinforcement
A_{tt}	=	total cross-sectional area of effective confining reinforcement within joint region for headed bars ($NA_{tr,l}$)
d_b	=	nominal diameter of headed bar
f_c'	=	specified concrete compressive strength
f_{cm}	=	measured average concrete compressive strength
$f_{s,ACI}$	=	stress in headed bar as calculated by Section 25.4.4.2 of ACI 318-14
f_y	=	yield strength of headed bar
ℓ_{dt}	=	development length in tension of headed deformed bar, measured from critical section to bearing face of the head
ℓ_{eh}	=	embedment length measured from front face of column to bearing face of the head
N	=	number of legs of confining reinforcement parallel to straight portion of headed bar within $8d_b$ from top of headed bar for No. 3 through No. 8 (No. 10 through No. 25) headed bars or $10d_b$ from top of headed bar for No. 9 through No. 11 (No. 29 through No. 36) headed bars
n	=	number of headed bars confined by N legs
T	=	average bar force at failure on headed bars in a specimen (failure load)
T_c	=	contribution of concrete to headed bar anchorage strength
T_h	=	headed bar anchorage strength
T_s	=	contribution of confining reinforcement oriented parallel to hooked or headed bar to anchorage strength
ψ_e	=	factor used to modify development length based on reinforcement coating as defined in ACI 318-14 Section 25.4.4.3

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APPENDIX A: NOTATION, CONVERSION FACTORS, HEAD DETAILS, REINFORCEMENT LAYOUTS, AND DATA TABLES

A.1 NOTATION AND CONVERSION FACTORS

Notation

A_{ab} Total cross-sectional area of all confining reinforcement parallel to ℓ_{dt} for headed bars being developed in beam-column joints and located within $8d_b$ of the bottom (top) of the headed bars in direction of the outside of the joint for No. 3 through No. 8 headed bars or within $10d_b$ of the bottom (top) of the bar in direction of the outside of the joint for No. 9 through No. 11 headed bars

A_b Area of an individual headed bar

A_{brg} Net bearing area of the head of headed deformed bar

A_{hs} Total cross-sectional area of headed bars being developed

$A_{tr,l}$ Area of single leg of confining reinforcement within joint region

A_{tt} Total cross-sectional area of all confining reinforcement parallel to ℓ_{dt} for headed bars being developed in beam-column joints and located within $8d_b$ of the top (bottom) of the headed bars in direction of the interior of the joint for No. 3 through No. 8 headed bars or within $10d_b$ of the top (bottom) of the bar in direction of the interior of the joint for No. 9 through No. 11 headed bars; or minimum total cross-sectional area of all confining reinforcement parallel to headed bars being developed in members other than beam-column joints within $7½d_b$ on one side of the bar centerline for No. 3 through No. 8 headed bars or within $9½d_b$ on one side of the bar centerline for No. 9 through No. 11 headed bars

b Width of column

c_{bc} Clear cover measured from the back of the head to the back of the member

c_h Clear spacing between adjacent headed bars

c_o Clear cover measured from the head to the side of the column

c_{sb} Clear cover measured from the bottom of the beam to the headed bar

c_{so} Clear cover measured from the side of the headed bar to the side of the member

$c_{so,\text{avg}}$ Average clear side cover of the headed bars

d_b Nominal diameter of bar

d_{eff} Effective value of d for beam-column joint

d_{tr} Nominal bar diameter of confining reinforcement within joint region

d_{tro} Nominal bar diameter of confining reinforcement outside joint region

f_{cm} Measured concrete compressive strength

f_{su} Average stress in headed bars at failure

$f_{su,\text{max}}$ Maximum stress in individual headed bar

h Depth of column

h_{cl} Height measured from the center of the headed bar to the top of the bearing member

ℓ_{dt} Development length in tension of headed deformed bar, measured from the critical section to the bearing face of the head

ℓ_{eh} Embedment length measured from the bearing face of the head to the face of the member

$\ell_{eh,\text{avg}}$ Average embedment length of headed bars

n Number of headed bars loaded simultaneously

N Number of legs of confining reinforcement in joint region

T Test failure load on a headed bar; average load on headed bars at failure

T_c Contribution of concrete to headed bar anchorage strength calculated using Eq. (3) or (4)

T_h Headed bar anchorage strength calculated using Eq. (7) or (8)

T_{ind} Peak load on individual headed bar at failure
T_{max} Maximum load on individual headed bar
T_{total} Sum of loads on headed bars at failure
c_{ch} Center-to-center spacing between adjacent headed bars
s_{tr} Center-to-center spacing of confining reinforcement (hoops) within joint region
s_{tro} Center-to-center spacing of hoops outside joint region

Failure types
CB Concrete breakout
SB Side blowout
FP Local front pullout (secondary failure)
BS Back cover spalling (secondary failure)
Y Yield of headed bars

Specimen identification
(A@B) C-D-E-F#G-H-I-J-K
A Number of headed bars in the specimen
B Center-to-center spacing between headed bars in terms of bar diameter
(A@B = blank, indicates specimens with 2 headed bars)
C ASTM in.-lb bar size
D Nominal compressive strength of concrete
E Head type
F Number of bars used as confining reinforcement within the joint region
G ASTM in.-lb bar size of confining reinforcement
(if F#G = 0 = no confining reinforcement)
H Hooked bars placed inside (i) or outside (o) of longitudinal reinforcement
I Nominal value of c_{so}
J Nominal value of c_{bc}
K Nominal value of ℓ_{eh}

Conversion Factors

1 in. = 25.4 mm

1 kip = 4.448 kN

1 ksi = 6.895 MPa

1 psi = 0.006895 MPa

Bar sizes: No. 3 (No. 10), No. 4 (No. 13), No. 5 (No. 16), No. 6 (No. 19), No. 7 (No. 22), No. 8 (No. 25), No. 9 (29), No. 10 (No. 32), No. 11 (No. 36)

A.2 DETAILS OF HEADS

Table A.1 Details of friction-forged headed bars

	Dimension Notation	Designation	Bar Size	*b* (in.)	*h* (in.)	*t* (in.)	d_{obs} (in.) [1]	t_{obs} (in.) [1]	Net Bearing Area (A_{brg}) [2]
Friction-Forged Headed Bars		F4.0	No. 5	1.25	1.25	0.5	0.93	0.46	$4.1A_b$
		F4.1 [3]	No. 8	2.02	2	1	1.54	0.60	$4.1A_b$
		F3.8	No. 11	2.5	3	1.375	2.11	0.73	$3.8A_b$
		F13.1	No. 5	1.25	3.5	0.5	0.93	0.46	$13.1A_b$
		F9.1 [3]	No. 8	2.03	3.98	1.02	1.58	0.62	$9.2A_b$
		F8.6	No. 11	2.5	6	1.375	2.11	0.73	$8.6A_b$

[1] See Fig. A1

[2] Net bearing area calculated as gross head area minus bar area. These heads contained obstructions adjacent to the bearing face of the head, as shown in Fig. A1, A3b, and A3c. These obstructions, however, did not have any detrimental effects on the anchorage strength of the headed bars and, therefore, are not considered to detract from the net bearing area of the head (Ghimire et al. 2018).

[3] Head dimensions updated from those given by Shao et al. (2016) (Ghimire et al. 2018)

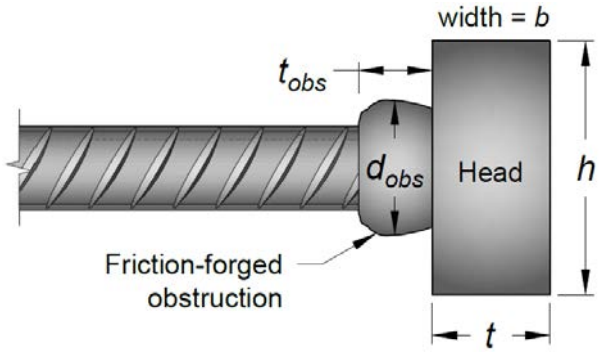
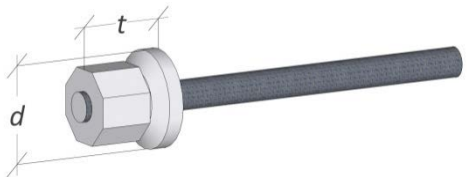


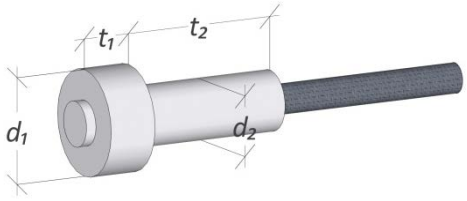
Fig. A1 Friction-forged obstruction adjacent to the bearing face of the head

Table A.1 Cont. Details of taper-threaded and cold-swaged headed bars

	Dimension Notation	Designation	Bar Size	d (in.)	t (in.)	Net Bearing Area (A_{brg}) [1]
Taper-Threaded Headed Bars		T4.0	No. 8	2.25	1.5	$4.0A_b$
		T9.5	No. 8	3.25	1.5	$9.5A_b$
Cold-Swaged Headed Bars		S4.0 [2] [3]	No. 6	1.63	1.52	$4.1A_b$
		S6.5 [2] [3]	No. 8	2.4	1.78	$5.0A_b$
		S5.5 [3]	No. 11	3.5	2.75	$5.5A_b$
		S9.5	No. 8	3.25	2.75	$9.5A_b$
		S14.9 [2]	No. 8	4.01	2.66	$15A_b$

[1] Net bearing area calculated as gross head area minus bar area
[2] Head dimensions updated from those given by Shao et al. (2016) (Ghimire et al. 2018)
[3] Octagonal head

Table A.1 Cont. Details of cold-swaged threaded coupling sleeve headed bars

	Dimension Notation	Designation	Bar Size	d_1 (in.)	t_1 (in.)	d_2 (in.)	t_2 (in.)	Net Bearing Area (A_{brg})
Cold-Swaged Threaded Coupling Sleeve Headed Bars		O4.5 [1]	No. 8	2.76	1.625	1.72 [2]	5.19	$4.6A_b$ [4]
						2.2 [3]		$2.8A_b$ [5]
		O4.5 [1]	No. 11	3.75	2.17	2.28 [2]	6.69	$4.5A_b$ [4]
						2.86 [3]		$3.0A_b$ [5]
		O9.1 [1]	No. 8	3.5	1.625	1.72 [2]	5.19	$9.2A_b$ [4]
						2.2 [3]		$7.4A_b$ [5]
		O12.9 [1]	No. 8	4	1.625	1.72 [2]	5.19	$13.0A_b$ [4]
						2.2 [3]		$11.2A_b$ [5]

[1] Head dimensions updated from those given by Shao et al. (2016). These heads contained obstructions with a gap (width not less than $^3/_8$ in.) adjacent to the bearing face of the head, as shown in Fig. A2 (Ghimire et al. 2018).
[2] Based on size of obstruction adjacent to head
[3] Based on maximum size of obstruction
[4] Net bearing area calculated as gross head area minus area of the obstruction adjacent to the bearing face of the head
[5] Net bearing area calculated as gross head area minus the maximum area of the obstruction

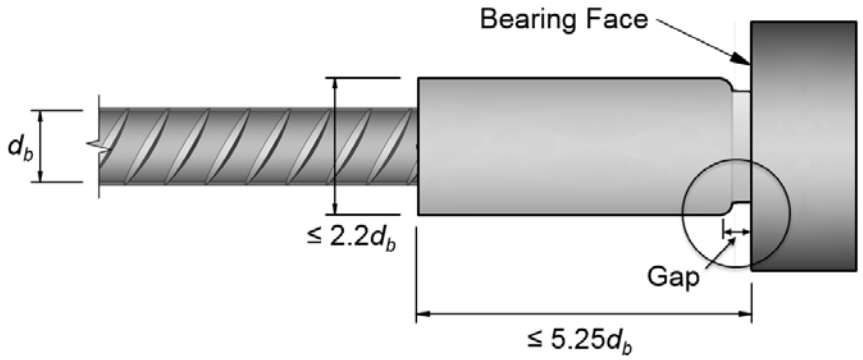
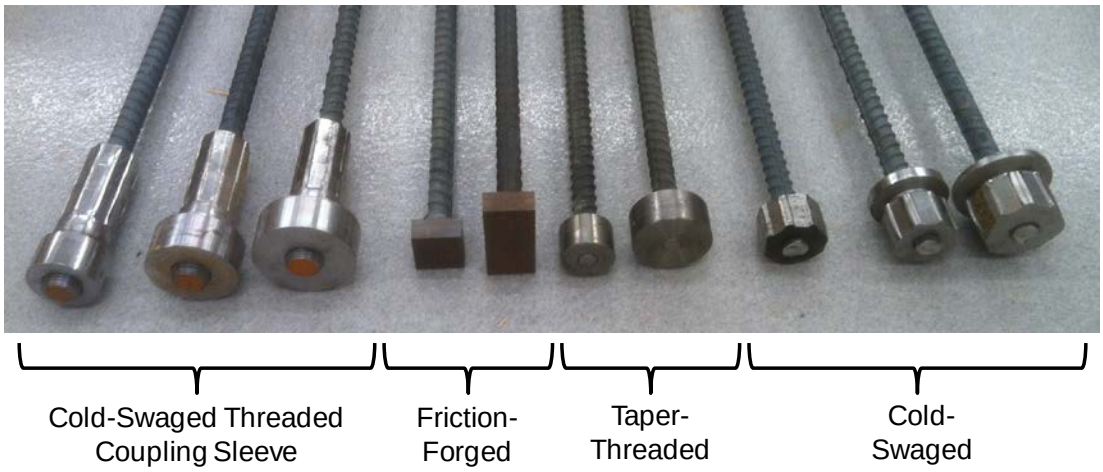
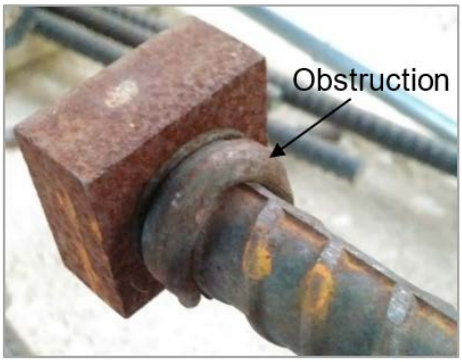


Fig. A2 Maximum dimensions and non-planner features of the obstruction

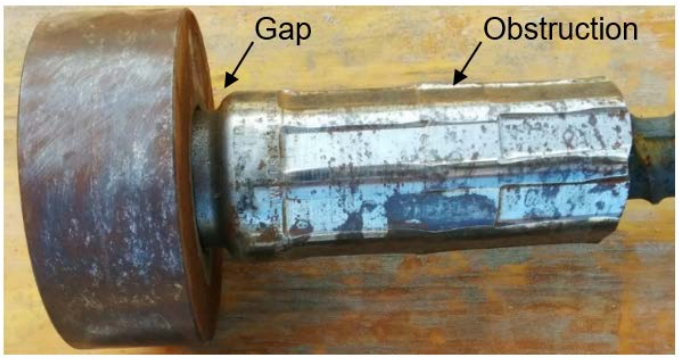


(a)



(b)

(c)



(d)

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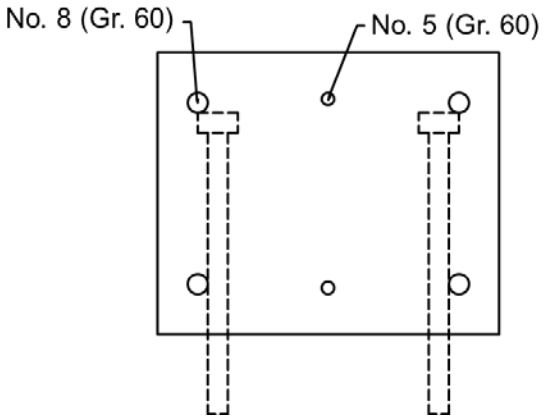
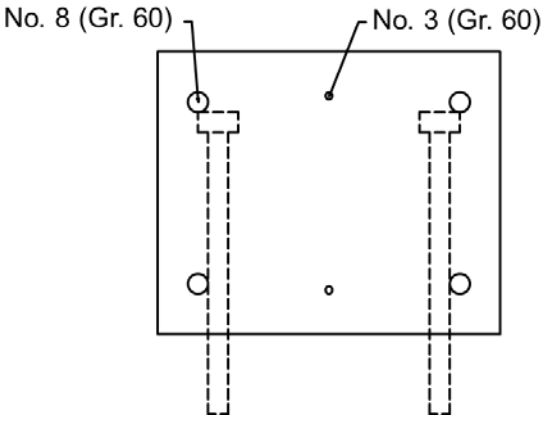
Fig. A3 (a) Left to right: cold-swaged threaded coupling sleeve, friction-forged, taper-threaded, and cold-swaged headed bars; (b) and (c) obstruction adjacent to the bearing face of the friction-forged heads; and (d) gap in the obstruction adjacent to the bearing face of the cold-swaged threaded coupling sleeve heads (taper-threaded and cold-swaged heads had no obstructions)

A.3 LONGITUDINAL COLUMN STEEL LAYOUTS

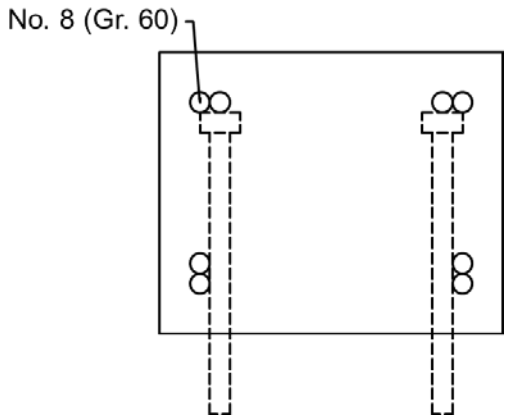
The longitudinal column reinforcement layouts A.1 through A.17 shown below may not reflect the real size, number, and location of headed bars. Confining reinforcement is omitted in the layouts for clarity.



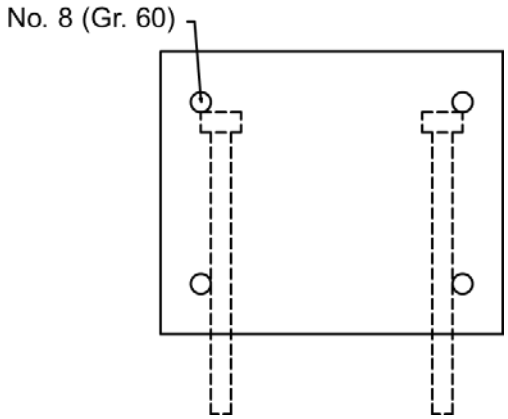
Layout A1 Layout B1: 4 No. 8 + 2 No. 5 (Gr. 60)



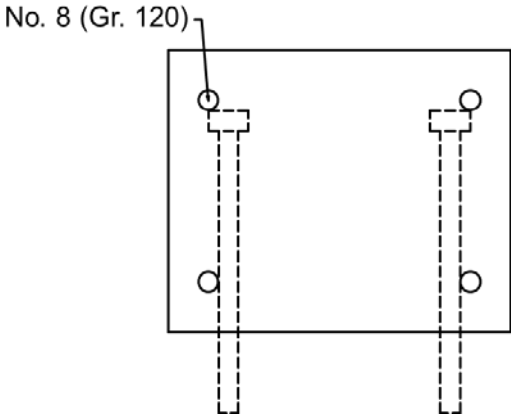
Layout A2 Layout B2: 4 No. 8 + 2 No. 3 (Gr. 60)



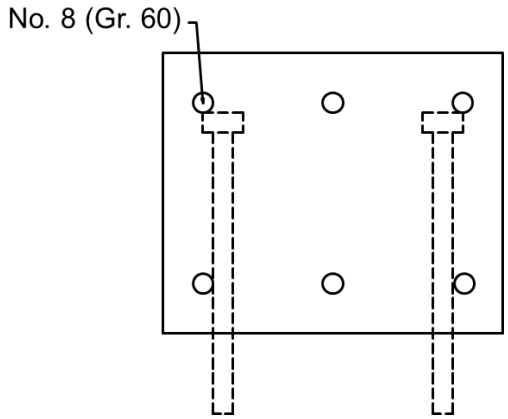
Layout A3 Layout B3: 8 No. 8 (Gr. 60), bundled at corner



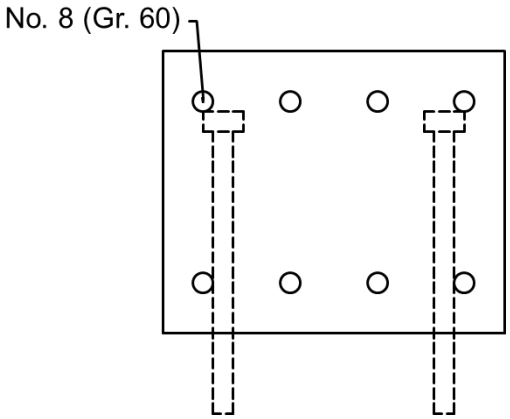
Layout A4 Layout B4: 4 No. 8 (Gr. 60)



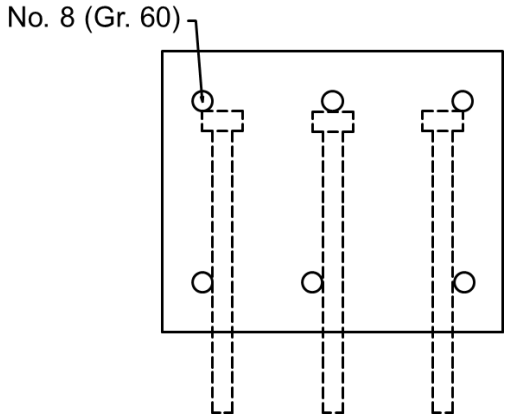
Layout A5 Layout B5: 4 No. 8 (Gr. 120)



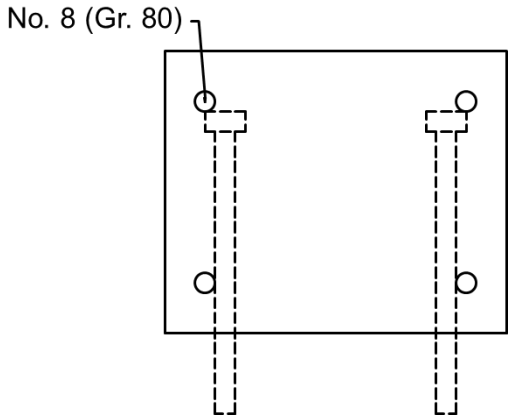
Layout A6 Layout B6: 6 No. 8 (Gr. 60)



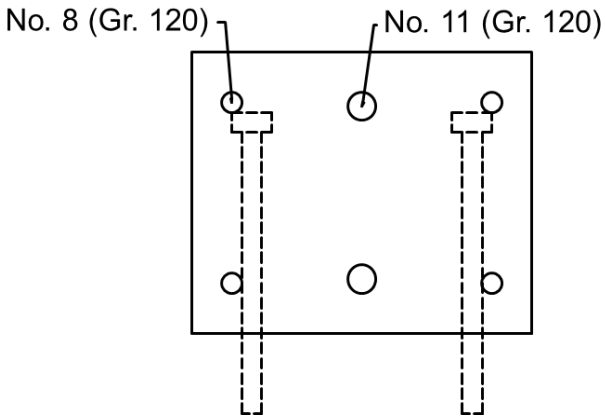
Layout A7 Layout B7: 8 No. 8 (Gr. 60)



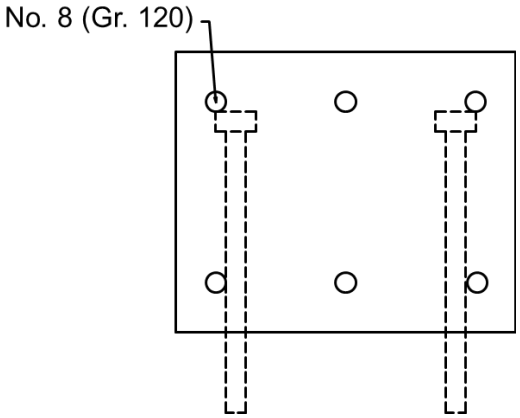
Layout A8 Layout B8: 6 No. 8 (Gr. 60), non-symmetric



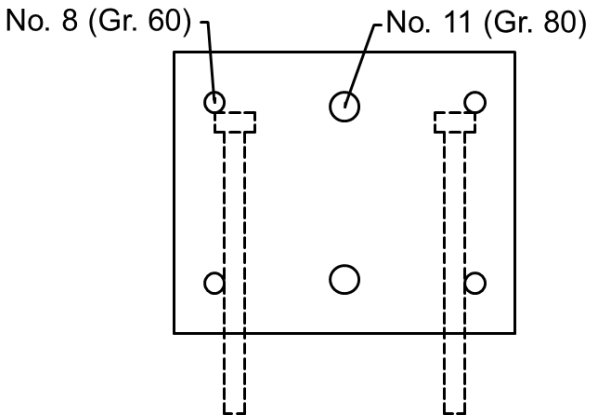
Layout A9 Layout B9: 4 No. 8 (Gr. 80)



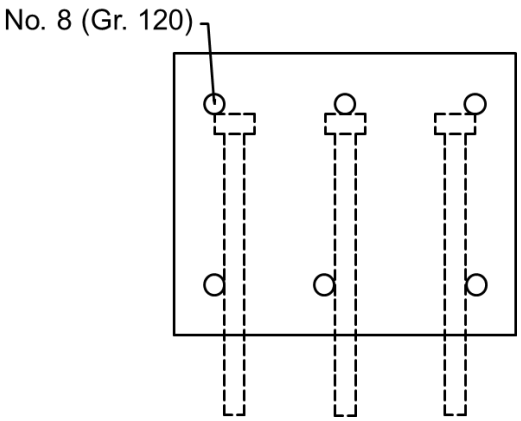
Layout A10 Layout B10: 4 No. 8 + 2 No. 11 (Gr. 120)



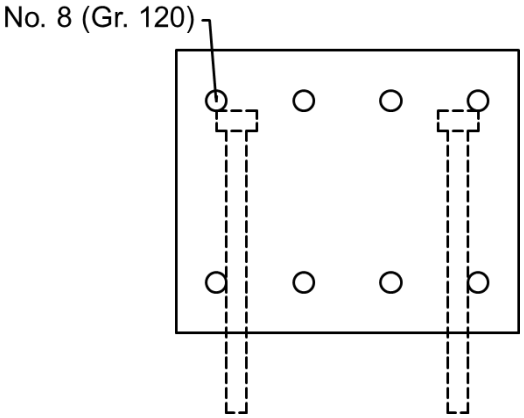
Layout A11 Layout B11: 6 No. 8 (Gr. 120)



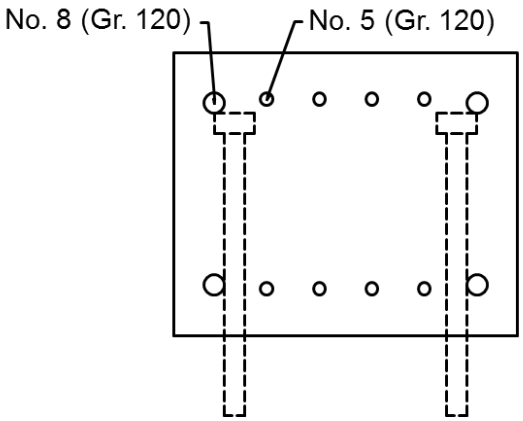
Layout A12 Layout B12: 4 No. 8 (Gr. 60) + 2 No. 11 (Gr. 80)



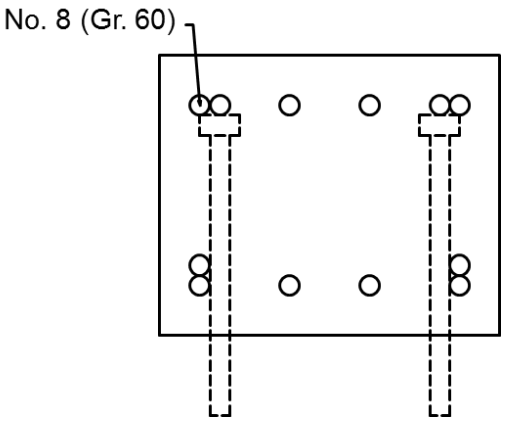
Layout A13 Layout B13: 6 No. 8 (Gr. 120), non-symmetric



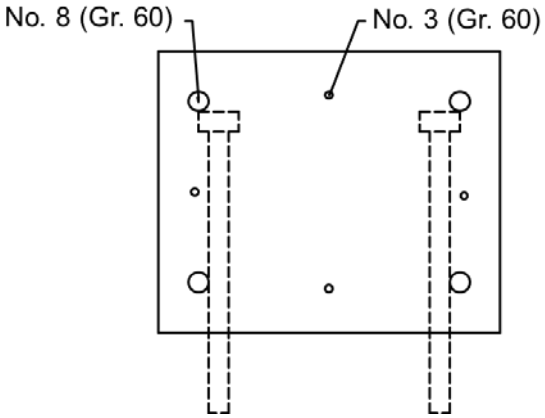
Layout A14 Layout B14: 8 No. 8 (Gr. 120)



Layout A15 Layout B15: 4 No. 8 +8 No. 5 (Gr. 120)



Layout A16 Layout B16: 12 No. 8 (Gr. 60)



Layout A17 Layout B17: 4 No. 8 + 4 No. 3 (Gr. 60)

A.4 TEST-TO-CALCULATED RATIOS

Table A.2 Test-to-calculated ratios for beam-column joint specimens with widely spaced headed bars and no confining reinforcement*

	Specimen	T kips	Descriptive Equation[a]	
			T_c kips	T/T_c
1	8-5g-T4.0-0-i-2.5-3-12.5	97.7	85.1	1.15
2	8-5g-T4.0-0-i-3.5-3-12.5	93.4	86.0	1.09
3	8-5-T4.0-0-i-2.5-3-12.5	83.3	86.3	0.96
4	8-5-T4.0-0-i-3.5-3-12.5	91.9	87.5	1.05
5	8-8-F4.1-0-i-2.5-3-10.5	77.1	77.1	1.00
6	8-12-F4.1-0-i-2.5-3-10	71.8	76.8	0.93
7	8-5-S6.5-0-i-2.5-3-11.25	75.6	73.4	1.03
8	8-5-S6.5-0-i-2.5-3-14.25	87.7	95.2	0.92
9	8-5-O4.5-0-i-2.5-3-11.25	67.4	74.6	0.90
10	8-5-O4.5-0-i-2.5-3-14.25	85.0	94.4	0.90
11	8-5-T9.5-0-i-2.5-3-14.5	91.7	93.8	0.98
12	8-5-O9.1-0-i-2.5-3-14.5	94.8	93.8	1.01
13	8-15-T4.0-0-i-2.5-4.5-9.5	83.3	81.1	1.03
14	8-15-S9.5-0-i-2.5-3-9.5	81.7	81.1	1.01
15	8-8-T9.5-0-i-2.5-3-9.5	65.2	69.7	0.94
16	(2@9)8-12-F4.1-0-i-2.5-3-12	79.1	96.9	0.82
17	(2@9)8-12-F9.1-0-i-2.5-3-12	76.5	95.3	0.80
18	8-8-O4.5-0-i-2.5-3-9.5	58.4	63.6	0.92
19	(2@9)8-8-O4.5-0-i-2.5-3-9.5	58.8	62.2	0.94
20	(2@9)8-8-T4.0-0-i-2.5-3-9.5	61.8	65.1	0.95
21	5-5-F4.0-0-i-2.5-5-4	24.5	21.5	1.14
22	5-5-F4.0-0-i-2.5-3-6	32.7	31.9	1.03
23	5-12-F4.0-0-i-2.5-5-4	28.3	26.2	1.08
24	5-12-F4.0-0-i-2.5-3-6	41.7	39.2	1.06
25	11-5a-F3.8-0-i-2.5-3-17	97.5	116.5	0.84
26	11-5-F3.8-0-i-2.5-3-17	132.7	132.2	1.00
27	11-12-O4.5-0-i-2.5-3-16.75	169.6	152.8	1.11
28	11-12-S5.5-0-i-2.5-3-16.75	175.9	148.5	1.18
29	11-5-O4.5-0-i-2.5-3-19.25	157.9	147.4	1.07
30	11-5-S5.5-0-i-2.5-3-19.25	176.8	152.4	1.16

* Specimens used to develop descriptive equations

[a] T_c based on Eq. (3)

Table A.2 Cont. Test-to-calculated ratios for beam-column joint specimens with closely spaced headed bars and no confining reinforcement*

	Specimen	T kips	Descriptive Equation[a]	
			T_c kips	T/T_c
31	(3@3)8-8-F4.1-0-i-2.5-3-10.5	54.8	46.3	1.18
32	(3@3)8-8-F4.1-0-i-2.5-3-10.5-HP	50.5	44.3	1.14
33	(3@4)8-8-F4.1-0-i-2.5-3-10.5	58.7	53.6	1.09
34	(3@5)8-8-F4.1-0-i-2.5-3-10.5	64.0	57.3	1.12
35	(3@5)8-8-F4.1-0-i-2.5-3-10.5-HP	59.9	57.4	1.04
36	(3@3)8-12-F4.1-0-i-2.5-3-10	42.2	46.4	0.91
37	(3@4)8-12-F4.1-0-i-2.5-3-10	48.9	53.0	0.92
38	(3@5)8-12-F4.1-0-i-2.5-3-10	55.1	60.0	0.92
39	(3@5.5)8-5-T9.5-0-i-2.5-3-14.5	73.4	74.7	0.98
40	(3@5.5)8-5-O9.1-0-i-2.5-3-14.5	75.7	75.3	1.01
41	(4@3.7)8-5-T9.5-0-i-2.5-3-14.5	60.8	63.1	0.96
42	(4@3.7)8-5-O9.1-0-i-2.5-3-14.5	61.2	61.0	1.00
43	(3@4)8-8-T9.5-0-i-2.5-3-9.5	40.3	46.7	0.86
44	(3@5)8-8-T9.5-0-i-2.5-3-9.5	44.5	55.1	0.81
45	(3@7)8-8-T9.5-0-i-2.5-3-9.5	68.7	67.2	1.02
46	(3@4)8-8-T9.5-0-i-2.5-3-14.5	76.6	74.6	1.03
47	(3@5)8-8-T9.5-0-i-2.5-3-14.5	93.2	84.5	1.10
48	(3@7)8-8-T9.5-0-i-2.5-3-14.5	104.0	104.8	0.99
49	(3@4.5)8-12-F4.1-0-i-2.5-3-12	75.2	69.9	1.08
50	(3@4.5)8-12-F9.1-0-i-2.5-3-12	75.4	69.6	1.08
51	(4@3)8-12-F4.1-0-i-2.5-3-12	49.3	57.3	0.86
52	(4@3)8-12-F9.1-0-i-2.5-3-12	50.3	58.5	0.86
53	(2@7)8-8-O4.5-0-i-2.5-3-9.5	54.5	59.5	0.92
54	(2@5)8-8-O4.5-0-i-2.5-3-9.5	51.2	48.7	1.05
55	(2@3)8-8-O4.5-0-i-2.5-3-9.5	47.7	37.7	1.27
56	(3@4.5)8-8-T4.0-0-i-2.5-3-9.5	40.7	46.7	0.87
57	(4@3)8-8-T4.0-0-i-2.5-3-9.5	26.2	38.7	0.68
58	(3@3)8-8-T4.0-0-i-2.5-3-9.5	39.4	39.8	0.99
59	(3@5.9)5-12-F4.0-0-i-2.5-4-5	28.0	27.7	1.01
60	(4@3.9)5-12-F4.0-0-i-2.5-4-5	25.6	22.3	1.15
61	(3@5.35)11-12-O4.5-0-i-2.5-3-16.75	106.8	118.5	0.90
62	(3@5.35)11-12-S5.5-0-i-2.5-3-16.75	109.0	117.1	0.93
63	(3@5.35)11-5-O4.5-0-i-2.5-3-19.25	128.7	117.3	1.10
64	(3@5.35)11-5-S5.5-0-i-2.5-3-19.25	137.4	119.7	1.15

* Specimens used to develop descriptive equations

[a] T_c based on Eq. (4)

Table A.2 Cont. Test-to-calculated ratios for beam-column joint specimens with widely spaced headed bars with confining reinforcement*

	Specimen	T kips	Descriptive Equation[a]	
			T_h kips	T/T_h
65	8-5-T4.0-4#3-i-3-3-12.5	87.5	96.9	0.90
66	8-5-T4.0-4#3-i-4-3-12.5	96.2	95.9	1.00
67	8-5-T4.0-4#4-i-3-3-12.5	109.0	100.7	1.08
68	8-5-T4.0-4#4-i-4-3-12.5	101.5	98.2	1.03
69	8-5g-T4.0-5#3-i-2.5-3-9.5	78.7	78.1	1.01
70	8-5g-T4.0-5#3-i-3.5-3-9.5	79.5	80.3	0.99
71	8-5g-T4.0-4#4-i-2.5-3-9.5	90.7	79.2	1.14
72	8-5g-T4.0-4#4-i-3.5-3-9.5	96.7	83.3	1.16
73	8-5-T4.0-5#3-i-2.5-3-9.5	74.2	78.7	0.94
74	8-5-T4.0-5#3-i-3.5-3-9.5	80.6	78.2	1.03
75	8-5-T4.0-4#4-i-2.5-3-9.5	90.5	82.9	1.09
76	8-5-T4.0-4#4-i-3.5-3-9.5	85.6	82.3	1.04
77	8-8-F4.1-2#3-i-2.5-3-10	73.4	77.7	0.94
78	8-12-F4.1-5#3-i-2.5-3-10	87.2	95.5	0.91
79	8-5-S6.5-2#3-i-2.5-3-9.25	63.4	66.2	0.96
80	8-5-S6.5-2#3-i-2.5-3-12.25	86.0	88.2	0.97
81	8-5-O4.5-2#3-i-2.5-3-9.25	67.9	67.9	1.00
82	8-5-O4.5-2#3-i-2.5-3-12.25	78.5	86.0	0.91
83	8-5-S6.5-5#3-i-2.5-3-8.25	62.0	71.7	0.87
84	8-5-S6.5-5#3-i-2.5-3-11.25	84.5	89.9	0.94
85	8-5-O4.5-5#3-i-2.5-3-8.25	68.4	69.5	0.98
86	8-5-O4.5-5#3-i-2.5-3-11.25	82.2	91.2	0.90
87	8-5-T9.5-5#3-i-2.5-3-14.5	121.0	111.9	1.08
88	8-15-T4.0-2#3-i-2.5-4.5-7	59.0	65.1	0.91
89	8-15-S9.5-2#3-i-2.5-3-7	67.1	65.1	1.03
90	8-15-T4.0-5#3-i-2.5-4.5-5.5	63.3	62.3	1.02
91	8-15-S9.5-5#3-i-2.5-3-5.5	75.8	63.4	1.20
92	8-8-T9.5-2#3-i-2.5-3-9.5	68.7	73.6	0.93
93	(2@9)8-12-F4.1-5#3-i-2.5-3-12	111.9	112.2	1.00
94	(2@9)8-8-T4.0-5#3-i-2.5-3-9.5	76.7	82.1	0.93
95	5-5-F4.0-2#3-i-2.5-5-4	19.7	23.7	0.83
96	5-5-F4.0-5#3-i-2.5-5-4	26.5	32.6	0.81
97	5-5-F4.0-2#3-i-2.5-3-6	37.9	35.4	1.07
98	5-5-F4.0-5#3-i-2.5-3-6	43.5	42.9	1.01
99	5-12-F4.0-2#3-i-2.5-5-4	32.7	30.2	1.08
100	5-12-F4.0-5#3-i-2.5-5-4	38.9	37.9	1.03
101	11-5a-F3.8-2#3-i-2.5-3-17	118.2	130.1	0.91
102	11-5a-F3.8-6#3-i-2.5-3-17	116.2	139.4	0.83
103	11-5-F3.8-6#3-i-2.5-3-17	151.9	152.7	1.00
104	11-12-O4.5-6#3-i-2.5-3-16.75	201.5	171.7	1.17
105	11-12-S5.5-6#3-i-2.5-3-16.75	197.4	169.2	1.17
106	11-5-O4.5-6#3-i-2.5-3-19.25	181.4	170.7	1.06
107	11-5-S5.5-6#3-i-2.5-3-19.25	189.6	172.1	1.10

* Specimens used to develop descriptive equations

[a] T_h based on Eq. (6)

Table A.2 Cont. Test-to-calculated ratios for beam-column joint specimens with closely spaced headed bars with confining reinforcement*

	Specimen	T kips	Descriptive Equation[a]	
			T_h kips	T/T_h
108	(3@3)8-8-F4.1-2#3-i-2.5-3-10	61.9	55.9	1.11
109	(3@3)8-8-F4.1-2#3-i-2.5-3-10-HP	56.7	57.4	0.99
110	(3@4)8-8-F4.1-2#3-i-2.5-3-10	55.5	59.4	0.93
111	(3@4)8-8-F4.1-2#3-i-2.5-3-10-HP	69.8	62.8	1.11
112	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5	56.1	62.8	0.89
113	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5-HP	65.5	65.6	1.00
114	(3@3)8-12-F4.1-5#3-i-2.5-3-10	61.6	65.2	0.95
115	(3@4)8-12-F4.1-5#3-i-2.5-3-10	65.7	69.3	0.95
116	(3@5)8-12-F4.1-5#3-i-2.5-3-10	69.7	74.6	0.93
117	(3@5.5)8-5-T9.5-5#3-i-2.5-3-14.5	94.6	94.7	1.00
118	(4@3.7)8-5-T9.5-5#3-i-2.5-3-14.5	76.9	81.7	0.94
119	(3@4)8-8-T9.5-2#3-i-2.5-3-9.5	51.8	59.3	0.87
120	(3@5)8-8-T9.5-2#3-i-2.5-3-9.5	55.9	64.2	0.87
121	(3@7)8-8-T9.5-2#3-i-2.5-3-9.5	67.6	75.6	0.89
122	(3@4)8-8-T9.5-2#3-i-2.5-3-14.5	85.4	88.8	0.96
123	(3@5)8-8-T9.5-2#3-i-2.5-3-14.5	105.2	95.6	1.10
124	(3@7)8-8-T9.5-2#3-i-2.5-3-14.5	113.4	113.8	1.00
125	(3@4.5)8-12-F4.1-5#3-i-2.5-3-12	87.7	89.0	0.99
126	(3@4.5)8-12-F9.1-5#3-i-2.5-3-12	108.6	87.3	1.24
127	(4@3)8-12-F4.1-5#3-i-2.5-3-12	64.2	77.0	0.83
128	(4@3)8-12-F9.1-5#3-i-2.5-3-12	87.8	76.3	1.15
129	(3@4.5)8-8-T4.0-5#3-i-2.5-3-9.5	62.5	61.7	1.01
130	(4@3)8-8-T4.0-5#3-i-2.5-3-9.5	48.6	54.8	0.89
131	(3@3)8-8-T4.0-5#3-i-2.5-3-9.5	56.5	55.1	1.03
132	(3@5.9)5-12-F4.0-2#3-i-2.5-4-5	35.1	32.8	1.07
133	(3@5.9)5-12-F4.0-5#3-i-2.5-4-5	38.6	36.1	1.07
134	(4@3.9)5-12-F4.0-2#3-i-2.5-4-5	30.9	27.1	1.14
135	(3@5.35)11-12-O4.5-6#3-i-2.5-3-16.75	135.8	145.6	0.93
136	(3@5.35)11-12-S5.5-6#3-i-2.5-3-16.75	153.8	140.5	1.09
137	(3@5.35)11-5-O4.5-6#3-i-2.5-3-19.25	141.7	141.9	1.00
138	(3@5.35)11-5-S5.5-6#3-i-2.5-3-19.25	152.9	144.9	1.06

* Specimens used to develop descriptive equations

[a] T_h based on Eq. (7)

A.5 COMPREHENSIVE TEST RESULTS

Table A.3 Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 1	8-5-T4.0-0-i-3-3-15.5[a] [b]	A B	2.4	4.0A_b	15.50 16.00	15.75	4850	7	1	0.79
	8-5-T4.0-0-i-4-3-15.5[a] [b]	A B	3.4	4.0A_b	15.50 15.06	15.28	5070	8	1	0.79
	8-5-T4.0-4#3-i-3-3-12.5[a]	A B	2.4	4.0A_b	12.06 12.69	12.38	5070	8	1	0.79
	8-5-T4.0-4#3-i-4-3-12.5[a]	A B	3.4	4.0A_b	11.94 12.19	12.06	5380	11	1	0.79
	8-5-T4.0-4#4-i-3-3-12.5[a]	A B	2.4	4.0A_b	12.56 12.31	12.44	5070	8	1	0.79
	8-5-T4.0-4#4-i-4-3-12.5[a]	A B	3.4	4.0A_b	12.06 12.31	12.19	4850	7	1	0.79
Group 2	8-5g-T4.0-0-i-2.5-3-12.5[a]	A B	1.9	4.0A_b	12.69 12.44	12.56	5910	14	1	0.79
	8-5g-T4.0-0-i-3.5-3-12.5[a]	A B	2.9	4.0A_b	12.44 12.56	12.50	6320	15	1	0.79
	8-5g-T4.0-5#3-i-2.5-3-9.5[a]	A B	1.9	4.0A_b	9.44 9.69	9.56	5090	7	1	0.79
	8-5g-T4.0-5#3-i-3.5-3-9.5[a]	A B	2.9	4.0A_b	9.69 9.44	9.56	5910	14	1	0.79
	8-5g-T4.0-4#4-i-2.5-3-9.5[a]	A B	1.9	4.0A_b	9.44 8.94	9.19	5180	8	1	0.79
	8-5g-T4.0-4#4-i-3.5-3-9.5[a]	A B	2.9	4.0A_b	9.31 9.69	9.50	5910	14	1	0.79
Group 3	8-5-T4.0-0-i-2.5-3-12.5[a]	A B	1.9	4.0A_b	12.69 12.50	12.59	6210	8	1	0.79
	8-5-T4.0-0-i-3.5-3-12.5[a]	A B	2.9	4.0A_b	12.81 12.50	12.66	6440	9	1	0.79
	8-5-T4.0-5#3-i-2.5-3-9.5[a]	A B	1.9	4.0A_b	9.44 9.19	9.31	5960	7	1	0.79
	8-5-T4.0-5#3-i-3.5-3-9.5[a]	A B	2.9	4.0A_b	9.06 9.06	9.06	6440	9	1	0.79
	8-5-T4.0-4#4-i-2.5-3-9.5[a]	A B	1.9	4.0A_b	9.19 9.31	9.25	6440	9	1	0.79
	8-5-T4.0-4#4-i-3.5-3-9.5[a]	A B	2.9	4.0A_b	9.56 8.94	9.25	6210	8	1	0.79
Group 4	8-8-F4.1-0-i-2.5-3-10.5	A B	2.0	4.1A_b	10.25 10.75	10.50	8450	9	1	0.79
	8-8-F4.1-2#3-i-2.5-3-10	A B	2.0	4.1A_b	9.75 10.00	9.88	8450	9	1	0.79
	(3@3)8-8-F4.1-0-i-2.5-3-10.5	A B C	2.0	4.1A_b	10.63 10.75 10.38	10.58	8450	9	1	0.79

[a] Specimen contained crossties within joint region
[b] Specimen had no confining reinforcement above joint region

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 1	8-5-T4.0-0-i-3-3-15.5[a] [b]	A B	17.9	20.3	10.25	12.94	3.0 2.9	3.0	3.3 2.8	11.0	-	-
	8-5-T4.0-0-i-4-3-15.5[a] [b]	A B	19.6	20.3	10.25	13.03	3.8 3.9	3.8	3.3 3.7	10.9	-	-
	8-5-T4.0-4#3-i-3-3-12.5[a]	A B	17.6	17.4	10.25	13.08	2.9 2.9	2.9	3.8 3.2	10.9	0.375	0.11
	8-5-T4.0-4#3-i-4-3-12.5[a]	A B	20.0	17.3	10.25	12.94	3.9 4.1	4.0	3.9 3.6	11.0	0.375	0.11
	8-5-T4.0-4#4-i-3-3-12.5[a]	A B	17.5	17.3	10.25	13.78	2.9 3.0	2.9	3.2 3.4	10.6	0.5	0.2
	8-5-T4.0-4#4-i-4-3-12.5[a]	A B	20.1	17.3	10.25	13.30	3.9 4.1	4.0	3.7 3.4	11.1	0.5	0.2
Group 2	8-5g-T4.0-0-i-2.5-3-12.5[a]	A B	16.8	17.2	10.25	13.28	2.5 2.5	2.5	3.0 3.3	10.8	-	-
	8-5g-T4.0-0-i-3.5-3-12.5[a]	A B	18.7	17.1	10.25	12.74	3.3 3.4	3.3	3.2 3.1	11.1	-	-
	8-5g-T4.0-5#3-i-2.5-3-9.5[a]	A B	17.3	14.1	10.25	12.94	2.8 2.8	2.8	3.2 2.9	10.8	0.375	0.11
	8-5g-T4.0-5#3-i-3.5-3-9.5[a]	A B	18.9	14.2	10.25	12.46	3.3 3.4	3.3	3.0 3.3	11.3	0.375	0.11
	8-5g-T4.0-4#4-i-2.5-3-9.5[a]	A B	16.5	14.1	10.25	13.32	2.5 2.5	2.5	3.2 3.7	10.5	0.5	0.2
	8-5g-T4.0-4#4-i-3.5-3-9.5[a]	A B	19.0	14.3	10.25	12.94	4.0 3.8	3.9	3.4 3.1	10.3	0.5	0.2
Group 3	8-5-T4.0-0-i-2.5-3-12.5[a]	A B	16.6	17.2	10.25	12.76	2.4 2.5	2.4	3.0 3.2	10.8	-	-
	8-5-T4.0-0-i-3.5-3-12.5[a]	A B	18.5	17.2	10.25	12.68	3.5 3.6	3.6	2.9 3.2	10.4	-	-
	8-5-T4.0-5#3-i-2.5-3-9.5[a]	A B	16.5	14.3	10.25	12.54	2.5 2.5	2.5	3.3 3.6	10.5	0.375	0.11
	8-5-T4.0-5#3-i-3.5-3-9.5[a]	A B	18.6	14.3	10.25	12.38	3.1 3.8	3.4	3.7 3.7	10.8	0.375	0.11
	8-5-T4.0-4#4-i-2.5-3-9.5[a]	A B	16.6	14.1	10.25	12.92	2.6 2.5	2.6	3.4 3.3	10.5	0.5	0.2
	8-5-T4.0-4#4-i-3.5-3-9.5[a]	A B	18.6	14.2	10.25	12.56	3.5 3.4	3.4	3.1 3.8	10.8	0.5	0.2
Group 4	8-8-F4.1-0-i-2.5-3-10.5	A B	16.8	14.8	10.25	12.19	2.4 2.5	2.4	3.5 3.0	10.9	-	-
	8-8-F4.1-2#3-i-2.5-3-10	A B	17.0	14.1	10.25	12.10	2.5 2.4	2.4	3.3 3.1	11.1	0.375	0.11
	(3@3)8-8-F4.1-0-i-2.5-3-10.5	A B C	11.9	14.6	10.25	13.18	2.5 - 2.4	2.4	3.0 2.8 3.2	3.0 3.0	-	-

[a] Specimen contained crossties within joint region
[b] Specimen had no confining reinforcement above joint region

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}[c] in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}[c] in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 1	8-5-T4.0-0-i-3-3-15.5[a b]	A B	-	-	-	-	-	-	2	1.58	A1
	8-5-T4.0-0-i-4-3-15.5[a b]	A B	-	-	-	-	-	-	2	1.58	A1
	8-5-T4.0-4#3-i-3-3-12.5[a]	A B	8	3 (1.5)	0.66	0.375	3 (1.5)	0.66	2	1.58	A2
	8-5-T4.0-4#3-i-4-3-12.5[a]	A B	8	3 (1.5)	0.66	0.375	3 (1.5)	0.66	2	1.58	A2
	8-5-T4.0-4#4-i-3-3-12.5[a]	A B	8	4 (2)	0.80	0.5	4 (2)	0.80	2	1.58	A17
	8-5-T4.0-4#4-i-4-3-12.5[a]	A B	8	4 (2)	0.80	0.5	4 (2)	0.80	2	1.58	A17
Group 2	8-5g-T4.0-0-i-2.5-3-12.5[a]	A B	-	-	-	0.375	3.5 (1.75)	0.44	2	1.58	A2
	8-5g-T4.0-0-i-3.5-3-12.5[a]	A B	-	-	-	0.375	3.5 (1.75)	0.44	2	1.58	A2
	8-5g-T4.0-5#3-i-2.5-3-9.5[a]	A B	10	3 (1.5)	0.66	0.375	3.5 (1.75)	0.44	2	1.58	A2
	8-5g-T4.0-5#3-i-3.5-3-9.5[a]	A B	10	3 (1.5)	0.66	0.375	3.5 (1.75)	0.44	2	1.58	A2
	8-5g-T4.0-4#4-i-2.5-3-9.5[a]	A B	8	4 (2)	0.80	0.5	3.5 (1.75)	0.80	2	1.58	A17
	8-5g-T4.0-4#4-i-3.5-3-9.5[a]	A B	8	4 (2)	0.80	0.5	3.5 (1.75)	0.80	2	1.58	A17
Group 3	8-5-T4.0-0-i-2.5-3-12.5[a]	A B	-	-	-	0.375	3.5 (1.75)	0.44	2	1.58	A2
	8-5-T4.0-0-i-3.5-3-12.5[a]	A B	-	-	-	0.375	3.5 (1.75)	0.44	2	1.58	A2
	8-5-T4.0-5#3-i-2.5-3-9.5[a]	A B	10	3 (1.5)	0.66	0.375	3.5 (1.75)	0.44	2	1.58	A2
	8-5-T4.0-5#3-i-3.5-3-9.5[a]	A B	10	3 (1.5)	0.66	0.375	3.5 (1.75)	0.44	2	1.58	A2
	8-5-T4.0-4#4-i-2.5-3-9.5[a]	A B	8	4 (2)	0.80	0.5	3.5 (1.75)	0.80	2	1.58	A17
	8-5-T4.0-4#4-i-3.5-3-9.5[a]	A B	8	4 (2)	0.80	0.5	3.5 (1.75)	0.80	2	1.58	A17
Group 4	8-8-F4.1-0-i-2.5-3-10.5	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A1
	8-8-F4.1-2#3-i-2.5-3-10	A B	4	5 (5.5)	0.22	0.375	4 (2)	0.44	2	1.58	A1
	(3@3)8-8-F4.1-0-i-2.5-3-10.5	A B C	-	-	-	0.375	3.5 (1.75)	0.44	3	2.37	A3

[a] Specimen contained crossties within joint region
[b] Specimen had no confining reinforcement above joint region
[c] Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 1	8-5-T4.0-0-i-3-3-15.5[a b]	A	SB/FP	0.019	81.6	103.3	81.6	160.9	80.4	101.8
		B		-	92.2	116.7	79.3			
	8-5-T4.0-0-i-4-3-15.5[a b]	A	SB/FP	0.308	92.5	117.1	92.5	190.9	95.4	120.8
		B		-	98.5	124.7	98.4			
	8-5-T4.0-4#3-i-3-3-12.5[a c]	A	SB/FP	0.227	87.9	111.3	87.9	175.0	87.5	110.8
		B		-	-[‡]	-[‡]	87.1			
	8-5-T4.0-4#3-i-4-3-12.5[a]	A	SB/FP	-	110.8	140.3	97.2	192.3	96.2	121.7
		B		0.239	95.2	120.5	95.1			
	8-5-T4.0-4#4-i-3-3-12.5[a]	A	SB/FP	0.049	109.5	138.6	109.4	218.1	109.0	138.0
		B		-	111.0	140.5	108.6			
	8-5-T4.0-4#4-i-4-3-12.5[a]	A	SB/FP	0.228	102.5	129.7	102.5	203.0	101.5	128.5
		B		0.350	103.4	130.9	100.5			
Group 2	8-5g-T4.0-0-i-2.5-3-12.5[a]	A	SB/FP	-	117.6	148.9	99.3	195.4	97.7	123.7
		B		0.022 (0.008)	96.1	121.6	96.1			
	8-5g-T4.0-0-i-3.5-3-12.5[a]	A	SB/FP	0.427	104.6	132.4	93.2	186.8	93.4	118.2
		B		(0.025)	93.6	118.5	93.6			
	8-5g-T4.0-5#3-i-2.5-3-9.5[a]	A	SB	0.190	78.9	99.9	78.9	157.4	78.7	99.6
		B		0.545	92.6	117.2	78.5			
	8-5g-T4.0-5#3-i-3.5-3-9.5[a]	A	SB	0.599	88.4	111.9	80.3	159.0	79.5	100.6
		B		0.193	78.7	99.6	78.7			
	8-5g-T4.0-4#4-i-2.5-3-9.5[a]	A	SB	0.187	92.2	116.7	92.2	181.5	90.7	114.8
		B		0.498 (0.032)	102.2	129.4	89.3			
	8-5g-T4.0-4#4-i-3.5-3-9.5[a]	A	SB	-	112.0	141.8	97.6	193.4	96.7	122.4
		B		(0.056)	95.8	121.3	95.8			
Group 3	8-5-T4.0-0-i-2.5-3-12.5[a]	A	SB/FP	-	84.0	106.3	84.0	166.6	83.3	105.4
		B		-	95.0	120.3	82.6			
	8-5-T4.0-0-i-3.5-3-12.5[a]	A	SB/FP	0.013	92.1	116.6	92.1	183.7	91.9	116.3
		B		-	100.1	126.7	91.6			
	8-5-T4.0-5#3-i-2.5-3-9.5[a]	A	SB	0.185	74.5	94.3	74.5	148.5	74.2	93.9
		B		0.163	74.0	93.7	74.0			
	8-5-T4.0-5#3-i-3.5-3-9.5[a]	A	SB/FP	-	80.7	102.2	80.7	161.1	80.6	102.0
		B		0.570	96.1	121.6	80.4			
	8-5-T4.0-4#4-i-2.5-3-9.5[a]	A	SB/FP	-	94.9	120.1	91.6	181.1	90.5	114.6
		B		(0.005)	89.5	113.3	89.5			
	8-5-T4.0-4#4-i-3.5-3-9.5[a]	A	SB/FP	0.186	86.6	109.6	86.6	171.1	85.6	108.4
		B		-	89.0	112.7	84.6			
Group 4	8-8-F4.1-0-i-2.5-3-10.5	A	CB	-	77.8	98.5	77.8	154.1	77.1	97.6
		B		-	76.3	96.6	76.3			
	8-8-F4.1-2#3-i-2.5-3-10	A	CB	0.107	73.5	93.0	73.5	146.8	73.4	92.9
		B		0.168	73.3	92.8	73.3			
	(3@3)8-8-F4.1-0-i-2.5-3-10.5	A	CB	0.170	49.0	62.0	49.0	164.3	54.8	69.4
		B		0.212	56.2	71.1	56.2			
		C		0.162	59.1	74.8	59.1			

[a] Specimen contained crossties within joint region
[b] Specimen had no confining reinforcement above joint region
[‡] No anchorage failure on the bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 4	(3@3)8-8-F4.1-0-i-2.5-3-10.5-HP	A B C	2.0	$4.1A_b$	10.13 10.13 10.75	10.33	8450	9	1	0.79
	(3@3)8-8-F4.1-2#3-i-2.5-3-10	A B C	2.0	$4.1A_b$	10.13 10.00 10.13	10.08	8260	8	1	0.79
	(3@3)8-8-F4.1-2#3-i-2.5-3-10-HP	A B C	2.0	$4.1A_b$	10.25 10.13 10.50	10.29	8260	8	1	0.79
	(3@4)8-8-F4.1-0-i-2.5-3-10.5	A B C	2.0	$4.1A_b$	10.88 10.75 10.88	10.83	8450	9	1	0.79
	(3@4)8-8-F4.1-2#3-i-2.5-3-10	A B C	2.0	$4.1A_b$	9.75 9.63 10.25	9.88	8050	7	1	0.79
	(3@4)8-8-F4.1-2#3-i-2.5-3-10-HP	A B C	2.0	$4.1A_b$	10.00 10.75 10.25	10.33	8050	7	1	0.79
	(3@5)8-8-F4.1-0-i-2.5-3-10.5	A B C	2.0	$4.1A_b$	10.50 10.38 10.19	10.35	8050	7	1	0.79
	(3@5)8-8-F4.1-0-i-2.5-3-10.5-HP	A B C	2.0	$4.1A_b$	9.75 10.50 10.50	10.25	8260	8	1	0.79
	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5	A B C	2.0	$4.1A_b$	9.63 9.75 10.00	9.79	8260	8	1	0.79
	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5-HP	A B C	2.0	$4.1A_b$	9.88 10.00 10.13	10.00	8260	8	1	0.79
Group 5	8-12-F4.1-0-i-2.5-3-10	A B	2.0	$4.1A_b$	9.63 9.75	9.69	11760	34	1	0.79
	8-12-F4.1-5#3-i-2.5-3-10	A B	2.0	$4.1A_b$	10.00 10.00	10.00	11760	34	1	0.79
	(3@3)8-12-F4.1-0-i-2.5-3-10	A B C	2.0	$4.1A_b$	9.81 10.00 9.88	9.90	11040	31	1	0.79
	(3@3)8-12-F4.1-5#3-i-2.5-3-10	A B C	2.0	$4.1A_b$	10.00 10.13 9.88	10.00	11040	31	1	0.79
	(3@4)8-12-F4.1-0-i-2.5-3-10	A B C	2.0	$4.1A_b$	10.00 9.75 10.00	9.92	11440	32	1	0.79

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 4	(3@3)8-8-F4.1-0-i-2.5-3-10.5-HP	A B C	11.8	14.6	10.25	12.95	2.5 - 2.5	2.5	3.4 3.4 2.8	3.0 2.8	-	-
	(3@3)8-8-F4.1-2#3-i-2.5-3-10	A B C	11.8	14.2	10.25	13.64	2.5 - 2.4	2.4	3.1 3.2 3.1	2.9 3.0	0.375	0.11
	(3@3)8-8-F4.1-2#3-i-2.5-3-10-HP	A B C	12.1	14.0	10.25	13.36	2.5 - 2.6	2.6	2.8 2.9 2.5	3.0 3.0	0.375	0.11
	(3@4)8-8-F4.1-0-i-2.5-3-10.5	A B C	13.9	14.7	10.25	12.94	2.5 - 2.5	2.5	2.8 3.0 2.8	3.9 4.0	-	-
	(3@4)8-8-F4.1-2#3-i-2.5-3-10	A B C	13.8	14.2	10.25	12.92	2.4 - 2.4	2.4	3.4 3.5 2.9	4.0 4.0	0.375	0.11
	(3@4)8-8-F4.1-2#3-i-2.5-3-10-HP	A B C	14.3	14.8	10.25	13.61	2.5 - 2.5	2.5	3.8 3.0 3.5	4.0 4.3	0.375	0.11
	(3@5)8-8-F4.1-0-i-2.5-3-10.5	A B C	15.9	14.7	10.25	12.95	2.5 - 2.4	2.5	3.2 3.3 3.5	4.9 5.1	-	-
	(3@5)8-8-F4.1-0-i-2.5-3-10.5-HP	A B C	16.0	14.8	10.25	12.71	2.4 - 2.5	2.4	4.0 3.3 3.3	5.1 5.0	-	-
	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5	A B C	15.3	14.2	10.25	12.55	2.4 - 2.4	2.4	3.6 3.4 3.2	4.8 4.8	0.375	0.11
	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5-HP	A B C	16.0	14.1	10.25	12.94	2.4 - 2.5	2.4	3.2 3.1 2.9	5.0 5.1	0.375	0.11
Group 5	8-12-F4.1-0-i-2.5-3-10	A B	16.9	14.2	10.25	11.55	2.4 2.6	2.5	3.5 3.4	10.9	0.375	-
	8-12-F4.1-5#3-i-2.5-3-10	A B	17.0	14.2	10.25	11.83	2.5 2.5	2.5	3.2 3.2	11.0	0.375	0.11
	(3@3)8-12-F4.1-0-i-2.5-3-10	A B C	12.0	14.2	10.25	11.98	2.5 - 2.4	2.4	3.3 3.2 3.3	3.1 3.0	0.375	-
	(3@3)8-12-F4.1-5#3-i-2.5-3-10	A B C	12.0	13.9	10.25	12.81	2.4 - 2.4	2.4	2.9 2.8 3.1	3.0 3.1	0.375	0.11
	(3@4)8-12-F4.1-0-i-2.5-3-10	A B C	14.0	14.0	10.25	11.91	2.5 - 2.5	2.5	3.0 3.3 3.0	4.0 4.0	0.375	-

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 4	(3@3)8-8-F4.1-0-i-2.5-3-10.5-HP	A B C	-	-	-	0.375	3.5 (1.75)	0.44	3	2.37	A3
	(3@3)8-8-F4.1-2#3-i-2.5-3-10	A B C	4	5 (5.5)	0.22	0.375	3 (1.5)	0.66	3	2.37	A3
	(3@3)8-8-F4.1-2#3-i-2.5-3-10-HP	A B C	4	5 (5.5)	0.22	0.375	3 (1.5)	0.66	3	2.37	A3
	(3@4)8-8-F4.1-0-i-2.5-3-10.5	A B C	-	-	-	0.375	4 (2)	0.44	3	2.37	A3
	(3@4)8-8-F4.1-2#3-i-2.5-3-10	A B C	4	5 (5.5)	0.22	0.375	3.5 (1.75)	0.44	3	2.37	A3
	(3@4)8-8-F4.1-2#3-i-2.5-3-10-HP	A B C	4	5 (5.5)	0.22	0.375	3.5 (1.75)	0.44	3	2.37	A3
	(3@5)8-8-F4.1-0-i-2.5-3-10.5	A B C	-	-	-	0.375	4 (2)	0.44	3	2.37	A3
	(3@5)8-8-F4.1-0-i-2.5-3-10.5-HP	A B C	-	-	-	0.375	4 (2)	0.44	3	2.37	A3
	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5	A B C	4	5 (5.5)	0.22	0.375	4 (2)	0.44	3	2.37	A3
	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5-HP	A B C	4	5 (5.5)	0.22	0.375	4 (2)	0.44	3	2.37	A3
Group 5	8-12-F4.1-0-i-2.5-3-10	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A4
	8-12-F4.1-5#3-i-2.5-3-10	A B	10	3 (1.5)	0.66	0.375	4 (2)	0.44	2	1.58	A5
	(3@3)8-12-F4.1-0-i-2.5-3-10	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@3)8-12-F4.1-5#3-i-2.5-3-10	A B C	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@4)8-12-F4.1-0-i-2.5-3-10	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A5

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 4	(3@3)8-8-F4.1-0-i-2.5-3-10.5-HP	A	CB/FP	0.399	55.3	70.0	55.3	151.4	50.5	63.9
		B		0.448	50.2	63.5	50.2			
		C		0.075	46.0	58.2	46.0			
	(3@3)8-8-F4.1-2#3-i-2.5-3-10	A	CB	0.097	53.2	67.3	53.2	185.8	61.9	78.4
		B		0.202	65.3	82.7	65.3			
		C		0.127	67.3	85.2	67.3			
	(3@3)8-8-F4.1-2#3-i-2.5-3-10-HP	A	CB	0.100	51.4	65.1	51.4	170.1	56.7	71.8
		B		0.150	58.7	74.3	58.7			
		C		0.151	60.0	75.9	60.0			
	(3@4)8-8-F4.1-0-i-2.5-3-10.5	A	CB	0.117	62.8	79.5	62.8	176.1	58.7	74.3
		B		0.339	62.3	78.9	62.3			
		C		0.146	51.4	65.1	51.0			
	(3@4)8-8-F4.1-2#3-i-2.5-3-10	A	CB	0.113	61.7	78.1	61.7	166.4	55.5	70.3
		B		0.213	52.9	67.0	52.9			
		C		0.203	51.8	65.6	51.8			
	(3@4)8-8-F4.1-2#3-i-2.5-3-10-HP	A	CB	0.143	70.6	89.4	70.5	209.5	69.8	88.4
		B		0.338	70.2	88.9	70.2			
		C		-	68.8	87.1	68.8			
	(3@5)8-8-F4.1-0-i-2.5-3-10.5	A	CB	0.255	67.9	85.9	67.9	192.0	64.0	81.0
		B		0.172	65.7	83.2	65.7			
		C		0.237	58.4	73.9	58.4			
	(3@5)8-8-F4.1-0-i-2.5-3-10.5-HP	A	CB	0.113	62.9	79.6	62.9	179.6	59.9	75.8
		B		-	60.8	77.0	60.8			
		C		-	55.9	70.8	55.9			
	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5	A	CB	-	61.4	77.7	61.4	168.2	56.1	71.0
		B		0.388	56.1	71.0	50.1			
		C		0.217	56.7	71.8	56.7			
	(3@5)8-8-F4.1-2#3-i-2.5-3-10.5-HP	A	CB	0.036	62.0	78.5	62.0	196.4	65.5	82.9
		B		0.171	70.8	89.6	70.8			
		C		0.168	63.6	80.5	63.6			
Group 5	8-12-F4.1-0-i-2.5-3-10	A	CB	0.110	72.5	91.8	72.5	143.6	71.8	90.9
		B		0.099 (0.079)	71.1	90.0	71.1			
	8-12-F4.1-5#3-i-2.5-3-10	A	SB/FP	-	88.4	111.9	88.4	174.3	87.2	110.4
		B		(0.006)	86.0	108.9	86.0			
	(3@3)8-12-F4.1-0-i-2.5-3-10	A	CB	-	38.5	48.7	38.5	126.5	42.2	53.4
		B		-	42.3	53.5	40.3			
		C		-	47.7	60.4	47.7			
	(3@3)8-12-F4.1-5#3-i-2.5-3-10	A	CB	0.230	65.7	83.2	65.7	187.4	61.6	78.0
		B		0.252	63.9	80.9	63.9			
		C		0.123	55.1	69.7	55.1			
	(3@4)8-12-F4.1-0-i-2.5-3-10	A	CB	0.120	49.1	62.2	49.1	146.6	48.9	61.9
		B		0.069	55.1	69.7	55.0			
		C		0.118 (0.043)	42.5	53.8	42.5			

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 5	(3@4)8-12-F4.1-5#3-i-2.5-3-10	A B C	2.0	4.1A_b	9.81 9.88 9.63	9.77	11440	32	1	0.79
	(3@5)8-12-F4.1-0-i-2.5-3-10	A B C	2.0	4.1A_b	9.88 10.13 9.75	9.92	11460	33	1	0.79
	(3@5)8-12-F4.1-5#3-i-2.5-3-10	A B C	2.0	4.1A_b	9.75 9.38 9.69	9.60	11460	33	1	0.79
Group 6	8-5-S6.5-0-i-2.5-3-11.25	A B	1.8	6.5A_b	11.00 11.13	11.06	5500	6	1	0.79
	8-5-S6.5-0-i-2.5-3-14.25	A B	1.8	6.5A_b	14.38 14.13	14.25	5500	6	1	0.79
	8-5-O4.5-0-i-2.5-3-11.25	A B	1.6	4.5A_b	11.00 11.50	11.25	5500	6	1	0.79
	8-5-O4.5-0-i-2.5-3-14.25	A B	1.6	4.5A_b	14.38 13.88	14.13	5500	6	1	0.79
	8-5-S6.5-2#3-i-2.5-3-9.25	A B	1.8	6.5A_b	9.25 9.00	9.13	5750	7	1	0.79
	8-5-S6.5-2#3-i-2.5-3-12.25	A B	1.8	6.5A_b	12.50 12.13	12.31	5750	7	1	0.79
	8-5-O4.5-2#3-i-2.5-3-9.25	A B	1.6	4.5A_b	9.38 9.38	9.38	5750	7	1	0.79
	8-5-O4.5-2#3-i-2.5-3-12.25	A B	1.6	4.5A_b	12.00 12.00	12.00	5750	7	1	0.79
	8-5-S6.5-5#3-i-2.5-3-8.25	A B	1.8	6.5A_b	8.38 8.25	8.31	5900	8	1	0.79
	8-5-S6.5-5#3-i-2.5-3-11.25	A B	1.8	6.5A_b	10.88 11.00	10.94	5900	8	1	0.79
	8-5-O4.5-5#3-i-2.5-3-8.25	A B	1.6	4.5A_b	8.13 7.88	8.00	5900	8	1	0.79
	8-5-O4.5-5#3-i-2.5-3-11.25	A B	1.6	4.5A_b	11.38 10.88	11.13	5900	8	1	0.79
Group 7	8-5-T9.5-0-i-2.5-3-14.5	A B	1.4	9.5A_b	14.25 14.50	14.38	4970	8	1	0.79
	8-5-O9.1-0-i-2.5-3-14.5	A B	1.3	9.1A_b	14.38 14.38	14.38	4970	8	1	0.79
	8-5-T9.5-5#3-i-2.5-3-14.5	A B	1.4	9.5A_b	14.50 14.25	14.38	5420	13	1	0.79
	8-5-O9.1-5#3-i-2.5-3-14.5	A B	1.3	9.1A_b	14.06 14.13	14.09	4970	8	1	0.79
	(3@5.5)8-5-T9.5-0-i-2.5-3-14.5	A B C	1.4	9.5A_b	14.25 14.25 14.25	14.25	4960	9	1	0.79

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 5	(3@4)8-12-F4.1-5#3-i-2.5-3-10	A B C	13.8	14.0	10.25	12.48	2.4 - 2.5	2.4	3.2 3.1 3.3	3.9 4.0	0.375	0.11
	(3@5)8-12-F4.1-0-i-2.5-3-10	A B C	16.1	14.1	10.25	11.88	2.5 - 2.5	2.5	3.2 3.0 3.3	5.0 5.1	0.375	-
	(3@5)8-12-F4.1-5#3-i-2.5-3-10	A B C	16.3	14.3	10.25	12.31	2.5 - 2.5	2.5	3.5 3.9 3.6	5.1 5.2	0.375	0.11
Group 6	8-5-S6.5-0-i-2.5-3-11.25	A B	16.8	16.1	10.25	12.70	2.5 2.5	2.5	3.4 3.3	10.8	0.375	-
	8-5-S6.5-0-i-2.5-3-14.25	A B	16.3	19.1	10.25	13.10	2.3 2.4	2.3	3.0 3.3	10.6	0.375	-
	8-5-O4.5-0-i-2.5-3-11.25	A B	16.9	16.1	10.25	12.44	2.5 2.5	2.5	3.5 3.0	10.9	0.375	-
	8-5-O4.5-0-i-2.5-3-14.25	A B	17.0	19.1	10.25	13.01	2.5 2.5	2.5	3.1 3.6	11.0	0.375	-
	8-5-S6.5-2#3-i-2.5-3-9.25	A B	17.5	14.0	10.25	12.25	2.8 2.5	2.6	3.0 3.3	11.3	0.375	0.11
	8-5-S6.5-2#3-i-2.5-3-12.25	A B	16.9	17.1	10.25	12.96	2.4 2.5	2.5	2.8 3.2	11.0	0.375	0.11
	8-5-O4.5-2#3-i-2.5-3-9.25	A B	17.0	14.1	10.25	12.39	2.5 2.5	2.5	3.1 3.1	11.0	0.375	0.11
	8-5-O4.5-2#3-i-2.5-3-12.25	A B	16.6	16.9	10.25	12.73	2.4 2.5	2.4	3.3 3.3	10.8	0.375	0.11
	8-5-S6.5-5#3-i-2.5-3-8.25	A B	16.9	13.1	10.25	12.18	2.5 2.4	2.4	3.0 3.1	11.0	0.375	0.11
	8-5-S6.5-5#3-i-2.5-3-11.25	A B	17.6	16.0	10.25	12.87	2.5 2.4	2.4	3.4 3.3	11.8	0.375	0.11
	8-5-O4.5-5#3-i-2.5-3-8.25	A B	17.3	13.0	10.25	12.37	2.5 2.8	2.6	3.3 3.5	11.0	0.375	0.11
	8-5-O4.5-5#3-i-2.5-3-11.25	A B	16.6	15.9	10.25	12.81	2.5 2.4	2.4	2.9 3.4	10.8	0.375	0.11
Group 7	8-5-T9.5-0-i-2.5-3-14.5	A B	17.0	19.1	10.25	13.43	2.6 2.5	2.6	3.4 3.1	10.9	0.375	-
	8-5-O9.1-0-i-2.5-3-14.5	A B	17.3	19.2	10.25	13.54	2.5 2.8	2.6	3.2 3.2	11.0	0.375	-
	8-5-T9.5-5#3-i-2.5-3-14.5	A B	17.1	19.2	10.25	14.22	2.5 2.6	2.6	3.2 3.5	11.0	0.375	0.11
	8-5-O9.1-5#3-i-2.5-3-14.5	A B	17.0	19.2	10.25	-‡	2.5 2.5	2.5	3.5 3.4	11.0	0.375	0.11
	(3@5.5)8-5-T9.5-0-i-2.5-3-14.5	A B C	16.9	19.2	10.25	14.08	2.4 - 2.5	2.4	3.4 3.4 3.4	5.5 5.5	0.375	-

‡ d_{eff} was not calculated for specimen with bar yielding

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 5	(3@4)8-12-F4.1-5#3-i-2.5-3-10	A B C	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@5)8-12-F4.1-0-i-2.5-3-10	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@5)8-12-F4.1-5#3-i-2.5-3-10	A B C	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	3	2.37	A5
Group 6	8-5-S6.5-0-i-2.5-3-11.25	A B	-	-	-	0.5	3.5 (1.75)	0.80	2	1.58	A4
	8-5-S6.5-0-i-2.5-3-14.25	A B	-	-	-	0.5	3.5 (1.75)	0.80	2	1.58	A4
	8-5-O4.5-0-i-2.5-3-11.25	A B	-	-	-	0.5	3.5 (1.75)	0.80	2	1.58	A4
	8-5-O4.5-0-i-2.5-3-14.25	A B	-	-	-	0.5	3.5 (1.75)	0.80	2	1.58	A4
	8-5-S6.5-2#3-i-2.5-3-9.25	A B	4	5.5 (5)	0.22	0.5	3 (1.5)	1.20	2	1.58	A4
	8-5-S6.5-2#3-i-2.5-3-12.25	A B	4	5.5 (5)	0.22	0.5	3 (1.5)	1.20	2	1.58	A4
	8-5-O4.5-2#3-i-2.5-3-9.25	A B	4	5.5 (5)	0.22	0.5	3 (1.5)	1.20	2	1.58	A4
	8-5-O4.5-2#3-i-2.5-3-12.25	A B	4	5.5 (5)	0.22	0.5	3 (1.5)	1.20	2	1.58	A4
	8-5-S6.5-5#3-i-2.5-3-8.25	A B	10	3 (1.5)	0.66	0.5	2.5 (1.25)	1.20	2	1.58	A4
	8-5-S6.5-5#3-i-2.5-3-11.25	A B	10	3 (1.5)	0.66	0.5	3 (1.5)	1.20	2	1.58	A4
	8-5-O4.5-5#3-i-2.5-3-8.25	A B	10	3 (1.5)	0.66	0.5	2.5 (1.25)	1.20	2	1.58	A4
	8-5-O4.5-5#3-i-2.5-3-11.25	A B	10	3 (1.5)	0.66	0.5	3 (1.5)	1.20	2	1.58	A4
Group 7	8-5-T9.5-0-i-2.5-3-14.5	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A4
	8-5-O9.1-0-i-2.5-3-14.5	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A4
	8-5-T9.5-5#3-i-2.5-3-14.5	A B	10	3 (1.5)	0.66	0.375	4 (2)	0.44	2	1.58	A6
	8-5-O9.1-5#3-i-2.5-3-14.5	A B	10	3 (1.5)	0.66	0.375	4 (2)	0.28	2	1.58	A6
	(3@5.5)8-5-T9.5-0-i-2.5-3-14.5	A B C	-	-	-	0.375	4 (2)	0.44	3	2.37	A5

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 5	(3@4)8-12-F4.1-5#3-i-2.5-3-10	A	CB/FP	0.138	64.0	81.0	64.0	197.1	65.7	83.2
		B		0.240	66.5	84.2	66.5			
		C		0.260	66.7	84.4	66.6			
	(3@5)8-12-F4.1-0-i-2.5-3-10	A	CB	0.079	57.1	72.3	57.1	165.4	55.1	69.7
		B		0.177	55.3	70.0	55.3			
		C		0.249 (0.081)	53.0	67.1	53.0			
	(3@5)8-12-F4.1-5#3-i-2.5-3-10	A	CB/FP	0.164	77.2	97.7	77.2	209.1	69.7	88.2
		B		0.123	65.4	82.8	65.4			
		C		0.122	66.7	84.4	66.6			
Group 6	8-5-S6.5-0-i-2.5-3-11.25	A	SB/FP	0.161	74.9	94.8	74.9	151.1	75.6	95.6
		B		-	76.2	96.5	76.2			
	8-5-S6.5-0-i-2.5-3-14.25	A	SB/FP	(0.054)	87.5	110.8	87.5	175.4	87.7	111.0
		B		-	103.4	130.9	88.0			
	8-5-O4.5-0-i-2.5-3-11.25	A	SB/FP	0.037	67.6	85.6	67.6	134.8	67.4	85.3
		B		0.198	67.2	85.0	67.2			
	8-5-O4.5-0-i-2.5-3-14.25	A	SB/FP	0.214 (0.023)	103.5	131.0	84.2	170.0	85.0	107.6
		B		0.113	85.8	108.6	85.8			
	8-5-S6.5-2#3-i-2.5-3-9.25	A	CB	(0.012)	62.6	79.2	62.6	126.7	63.4	80.2
		B		-	64.1	81.2	64.1			
	8-5-S6.5-2#3-i-2.5-3-12.25	A	SB/FP	0.340	84.6	107.1	84.6	171.9	86.0	108.8
		B		0.254	89.3	113.0	87.3			
	8-5-O4.5-2#3-i-2.5-3-9.25	A	SB/FP	0.309	67.6	85.6	67.1	135.8	67.9	86.0
		B		0.205	68.7	86.9	68.7			
	8-5-O4.5-2#3-i-2.5-3-12.25	A	SB/FP	0.305	82.8	104.8	77.4	157.0	78.5	99.4
		B		0.220	79.6	100.8	79.6			
	8-5-S6.5-5#3-i-2.5-3-8.25	A	CB/FP	0.363	61.9	78.4	61.9	124.1	62.0	78.5
		B		0.500	62.2	78.7	62.2			
	8-5-S6.5-5#3-i-2.5-3-11.25	A	SB/FP	-	100.8	127.6	84.2	169.0	84.5	106.9
		B		0.046	84.7	107.2	84.7			
	8-5-O4.5-5#3-i-2.5-3-8.25	A	SB/FP	0.457	68.3	86.5	68.3	136.8	68.4	86.6
		B		0.383	68.5	86.7	68.5			
	8-5-O4.5-5#3-i-2.5-3-11.25	A	SB/FP	0.171	85.0	107.6	82.1	164.5	82.2	104.1
		B		-	82.4	104.3	82.4			
Group 7	8-5-T9.5-0-i-2.5-3-14.5	A	SB/FP	0.130	91.5	115.8	91.5	183.3	91.7	116.0
		B		0.312	115.9	146.7	91.8			
	8-5-O9.1-0-i-2.5-3-14.5	A	SB/FP	0.060	94.6	119.7	94.6	189.6	94.8	120.0
		B		0.186	95.2	120.5	95.0			
	8-5-T9.5-5#3-i-2.5-3-14.5	A	SB/FP	-	120.7[‡]	152.8[‡]	120.6	242.0	121.0	153.2
		B		-	121.4	153.7	121.4			
	8-5-O9.1-5#3-i-2.5-3-14.5	A	Y	0.050	118.8	150.4	118.8	238.5	119.3	150.9
		B		-	119.7	151.5	119.7			
	(3@5.5)8-5-T9.5-0-i-2.5-3-14.5	A	CB	0.156	68.7	87.0	68.7	220.2	73.4	92.9
		B		0.138	78.8	99.7	78.8			
		C		0.217	72.6	91.9	72.6			

[‡] No anchorage failure on the bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 7	(3@5.5)8-5-O9.1-0-i-2.5-3-14.5	A B C	1.3	9.1A_b	14.31 14.50 14.25	14.35	4960	9	1	0.79
	(3@5.5)8-5-T9.5-5#3-i-2.5-3-14.5	A B C	1.4	9.5A_b	14.50 14.38 14.38	14.42	5370	10	1	0.79
	(3@5.5)8-5-O9.1-5#3-i-2.5-3-14.5	A B C	1.3	9.1A_b	14.06 14.44 14.31	14.27	5420	13	1	0.79
	(4@3.7)8-5-T9.5-0-i-2.5-3-14.5	A B C D	1.4	9.5A_b	14.25 14.38 14.25 14.19	14.30	5570	14	1	0.79
	(4@3.7)8-5-O9.1-0-i-2.5-3-14.5	A B C D	1.3	9.1A_b	14.06 14.06 14.06 14.06	14.06	5570	14	1	0.79
	(4@3.7)8-5-T9.5-5#3-i-2.5-3-14.5	A B C D	1.4	9.5A_b	14.44 14.38 14.63 14.50	14.50	5570	14	1	0.79
	(4@3.7)8-5-O9.1-5#3-i-2.5-3-14.5	A B C D	1.3	9.1A_b	14.44 14.44 14.63 14.44	14.50	5570	14	1	0.79
Group 8	8-15-T4.0-0-i-2.5-4.5-9.5	A B	1.9	4.0A_b	9.50 9.50	9.50	16030	88	1	0.79
	8-15-S9.5-0-i-2.5-3-9.5	A B	1.4	9.5A_b	9.50 9.50	9.50	16030	88	1	0.79
	8-15-S14.9-0-i-2.5-3-9.5	A B	1.0	14.9A_b	9.63 9.75	9.69	16030	88	1	0.79
	8-15-T4.0-2#3-i-2.5-4.5-7	A B	1.9	4.0A_b	7.13 7.00	7.06	16030	87	1	0.79
	8-15-S9.5-2#3-i-2.5-3-7	A B	1.4	9.5A_b	7.13 7.00	7.06	16030	87	1	0.79
	8-15-S14.9-2#3-i-2.5-3-7	A B	1.0	14.9A_b	7.00 7.00	7.00	16030	87	1	0.79
	8-15-T4.0-5#3-i-2.5-4.5-5.5	A B	1.9	4.0A_b	5.50 5.50	5.50	16030	88	1	0.79
	8-15-S9.5-5#3-i-2.5-3-5.5	A B	1.4	9.5A_b	5.75 5.50	5.63	16030	88	1	0.79
	8-15-S14.9-5#3-i-2.5-3-5.5	A B	1.0	14.9A_b	5.50 5.50	5.50	16030	88	1	0.79

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 7	(3@5.5)8-5-O9.1-0-i-2.5-3-14.5	A B C	16.9	19.2	10.25	14.20	2.4 - 2.5	2.4	3.3 3.1 3.3	5.5 5.5	0.375	-
	(3@5.5)8-5-T9.5-5#3-i-2.5-3-14.5	A B C	17.4	19.1	10.25	14.93	2.5 - 2.8	2.6	3.1 3.2 3.2	5.6 5.5	0.375	0.11
	(3@5.5)8-5-O9.1-5#3-i-2.5-3-14.5	A B C	17.3	19.2	10.25	-‡	2.5 - 2.5	2.5	3.5 3.2 3.3	5.8 5.5	0.375	0.11
	(4@3.7)8-5-T9.5-0-i-2.5-3-14.5	A B C D	17.3	19.2	10.25	14.17	2.5 - - 2.5	2.5	3.5 3.3 3.5 3.5	3.8 3.8 3.8	0.375	-
	(4@3.7)8-5-O9.1-0-i-2.5-3-14.5	A B C D	16.8	19.1	10.25	14.19	2.5 - - 2.4	2.4	3.4 3.4 3.4 3.4	3.6 3.8 3.5	0.375	-
	(4@3.7)8-5-T9.5-5#3-i-2.5-3-14.5	A B C D	17.1	19.1	10.25	15.20	2.4 - - 2.5	2.4	3.2 3.2 3.0 3.1	3.8 3.8 3.8	0.375	0.11
	(4@3.7)8-5-O9.1-5#3-i-2.5-3-14.5	A B C D	16.9	19.1	10.25	-‡	2.5 - - 2.5	2.5	3.1 3.1 2.9 3.1	3.6 3.6 3.6	0.375	0.11
Group 8	8-15-T4.0-0-i-2.5-4.5-9.5	A B	17.0	15.5	10.25	11.36	2.5 2.5	2.5	4.5 4.5	11.0	0.375	-
	8-15-S9.5-0-i-2.5-3-9.5	A B	17.3	15.2	10.25	11.33	2.8 2.5	2.6	2.9 2.9	11.0	0.375	-
	8-15-S14.9-0-i-2.5-3-9.5	A B	16.8	15.3	10.25	11.41	2.5 2.5	2.5	2.9 2.8	10.8	0.375	-
	8-15-T4.0-2#3-i-2.5-4.5-7	A B	17.0	13.1	10.25	11.03	2.5 2.5	2.5	4.5 4.6	11.0	0.375	0.11
	8-15-S9.5-2#3-i-2.5-3-7	A B	16.9	13.1	10.25	11.14	2.5 2.5	2.5	3.2 3.3	10.9	0.375	0.11
	8-15-S14.9-2#3-i-2.5-3-7	A B	17.6	13.1	10.25	11.30	2.8 2.9	2.8	3.3 3.3	11.0	0.375	0.11
	8-15-T4.0-5#3-i-2.5-4.5-5.5	A B	16.9	11.7	10.25	11.09	2.4 2.5	2.4	4.7 4.7	11.0	0.375	0.11
	8-15-S9.5-5#3-i-2.5-3-5.5	A B	16.8	11.5	10.25	11.26	2.3 2.5	2.4	3.0 3.3	11.0	0.375	0.11
	8-15-S14.9-5#3-i-2.5-3-5.5	A B	17.0	12.0	10.25	11.33	2.5 2.5	2.5	3.8 3.8	11.0	0.375	0.11

‡ d_{eff} was not calculated for specimen with bar yielding

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 7	(3@5.5)8-5-O9.1-0-i-2.5-3-14.5	A B C	-	-	-	0.375	4 (2)	0.44	3	2.37	A5
	(3@5.5)8-5-T9.5-5#3-i-2.5-3-14.5	A B C	10	3 (1.5)	0.66	0.375	4 (2)	0.44	3	2.37	A5
	(3@5.5)8-5-O9.1-5#3-i-2.5-3-14.5	A B C	10	3 (1.5)	0.66	0.375	4 (2)	0.19	3	2.37	A5
	(4@3.7)8-5-T9.5-0-i-2.5-3-14.5	A B C D	-	-	-	0.375	4 (2)	0.44	4	3.16	A5
	(4@3.7)8-5-O9.1-0-i-2.5-3-14.5	A B C D	-	-	-	0.375	4 (2)	0.44	4	3.16	A5
	(4@3.7)8-5-T9.5-5#3-i-2.5-3-14.5	A B C D	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	4	3.16	A5
	(4@3.7)8-5-O9.1-5#3-i-2.5-3-14.5	A B C D	10	3 (1.5)	0.66	0.375	3 (1.5)	0.21	4	3.16	A5
Group 8	8-15-T4.0-0-i-2.5-4.5-9.5	A B	-	-	-	0.5	4 (2)	0.80	2	1.58	A6
	8-15-S9.5-0-i-2.5-3-9.5	A B	-	-	-	0.5	4 (2)	0.80	2	1.58	A6
	8-15-S14.9-0-i-2.5-3-9.5	A B	-	-	-	0.5	4 (2)	0.80	2	1.58	A6
	8-15-T4.0-2#3-i-2.5-4.5-7	A B	4	5.5 (5)	0.22	0.5	4 (2)	0.80	2	1.58	A6
	8-15-S9.5-2#3-i-2.5-3-7	A B	4	5.5 (5)	0.22	0.5	4 (2)	0.80	2	1.58	A6
	8-15-S14.9-2#3-i-2.5-3-7	A B	4	5.5 (5)	0.22	0.5	4 (2)	0.80	2	1.58	A6
	8-15-T4.0-5#3-i-2.5-4.5-5.5	A B	10	3 (1.5)	0.66	0.5	4 (2)	0.80	2	1.58	A7
	8-15-S9.5-5#3-i-2.5-3-5.5	A B	10	3 (1.5)	0.66	0.5	4 (2)	0.80	2	1.58	A7
	8-15-S14.9-5#3-i-2.5-3-5.5	A B	10	3 (1.5)	0.66	0.5	4 (2)	0.80	2	1.58	A7

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 7	(3@5.5)8-5-O9.1-0-i-2.5-3-14.5	A	CB	0.081 (0.043)	91.0	115.2	91.0	227.1	75.7	95.8
		B		0.085	76.2	96.5	76.2			
		C		0.055	59.9	75.8	59.9			
	(3@5.5)8-5-T9.5-5#3-i-2.5-3-14.5	A	CB	0.121	91.5	115.8	91.5	283.8	94.6	119.7
		B		0.086	91.5	115.8	91.5			
		C		0.223	100.8	127.6	100.8			
	(3@5.5)8-5-O9.1-5#3-i-2.5-3-14.5	A	Y	-	115.4	146.1	102.9	306.6	102.2	129.4
		B		-	104.4	132.2	100.4			
		C		-	103.3	130.8	103.3			
	(4@3.7)8-5-T9.5-0-i-2.5-3-14.5	A	CB	0.159	89.7	113.5	89.7	243.3	60.8	77.0
		B		0.236	46.9	59.4	46.9			
		C		-	57.6	72.9	57.6			
		D		0.168	49.1	62.2	49.1			
	(4@3.7)8-5-O9.1-0-i-2.5-3-14.5	A	CB	0.088	67.9	85.9	67.9	244.9	61.2	77.5
		B		-	69.7	88.2	69.7			
		C		-	56.6	71.6	56.6			
		D		0.114 (0.085)	50.8	64.3	50.8			
	(4@3.7)8-5-T9.5-5#3-i-2.5-3-14.5	A	CB	0.320	-†	-†	-	-†	76.9†	97.3
		B		-	82.2	104.1	82.2			
		C		-	74.6	94.4	74.6			
		D		0.161	73.8	93.4	73.8			
	(4@3.7)8-5-O9.1-5#3-i-2.5-3-14.5	A	Y	0.087	-†	-†	-	-†	89.1†	112.8
		B		0.016	97.1	122.9	96.8			
		C		-	88.9	112.5	88.9			
		D		0.033	81.4	103.0	81.4			
Group 8	8-15-T4.0-0-i-2.5-4.5-9.5	A	CB	-	83.2	105.3	83.2	166.6	83.3	105.4
		B		0.237	83.4	105.6	83.4			
	8-15-S9.5-0-i-2.5-3-9.5	A	CB	-	83.5	105.7	83.5	163.3	81.7	103.4
		B		-	79.9	101.1	79.9			
	8-15-S14.9-0-i-2.5-3-9.5	A	CB	-	88.2	111.6	88.2	174.2	87.1	110.3
		B		-	86.1	109.0	86.1			
	8-15-T4.0-2#3-i-2.5-4.5-7	A	CB	-	59.1	74.8	59.1	118.0	59.0	74.7
		B		-	58.9	74.6	58.9			
	8-15-S9.5-2#3-i-2.5-3-7	A	CB	-	66.4	84.1	66.4	134.3	67.1	84.9
		B		-	67.9	85.9	67.9			
	8-15-S14.9-2#3-i-2.5-3-7	A	CB	-	79.7	100.9	79.7	158.7	79.3	100.4
		B		-	78.9	99.9	78.9			
	8-15-T4.0-5#3-i-2.5-4.5-5.5	A	CB	-	64.0	81.0	64.0	126.6	63.3	80.1
		B		-	62.6	79.2	62.6			
	8-15-S9.5-5#3-i-2.5-3-5.5	A	CB	-	76.6	97.0	76.6	151.6	75.8	95.9
		B		-	75.0	94.9	75.0			
	8-15-S14.9-5#3-i-2.5-3-5.5	A	CB	-	80.7	102.2	80.7	162.7	81.4	103.0
		B		-	82.0	103.8	82.0			

† Load on headed bar A was not recorded due to a malfunction of load cell; T taken as the average load of the other three bars.

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 9	8-8-T9.5-0-i-2.5-3-9.5	A B	1.4	$9.5A_b$	9.50 9.25	9.38	9040	12	1	0.79
	8-8-T9.5-2#3-i-2.5-3-9.5	A B	1.4	$9.5A_b$	9.00 9.38	9.19	9040	12	1	0.79
	(3@4)8-8-T9.5-0-i-2.5-3-9.5	A B C	1.4	$9.5A_b$	9.00 9.50 9.25	9.25	9040	12	1	0.79
	(3@4)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	1.4	$9.5A_b$	9.75 9.50 9.50	9.58	9040	12	1	0.79
	(3@5)8-8-T9.5-0-i-2.5-3-9.5	A B C	1.4	$9.5A_b$	9.50 9.75 9.25	9.50	9940	11	1	0.79
	(3@5)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	1.4	$9.5A_b$	9.50 9.50 9.25	9.42	9940	11	1	0.79
	(3@7)8-8-T9.5-0-i-2.5-3-9.5	A B C	1.4	$9.5A_b$	9.50 9.63 9.38	9.50	10180	10	1	0.79
	(3@7)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	1.4	$9.5A_b$	9.50 9.75 9.50	9.58	10180	10	1	0.79
	8-8-T9.5-0-i-2.5-3-14.5	A B	1.4	$9.5A_b$	14.50 14.25	14.38	10180	10	1	0.79
	(3@4)8-8-T9.5-0-i-2.5-3-14.5	A B C	1.4	$9.5A_b$	14.25 14.75 14.75	14.58	9040	12	1	0.79
	(3@4)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	1.4	$9.5A_b$	14.50 14.50 14.25	14.42	9040	12	1	0.79
	(3@5)8-8-T9.5-0-i-2.5-3-14.5	A B C	1.4	$9.5A_b$	14.75 14.50 14.50	14.58	9940	11	1	0.79
	(3@5)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	1.4	$9.5A_b$	14.00 14.25 14.00	14.08	9940	11	1	0.79
	(3@7)8-8-T9.5-0-i-2.5-3-14.5	A B C	1.4	$9.5A_b$	14.44 14.56 14.63	14.54	10180	10	1	0.79
	(3@7)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	1.4	$9.5A_b$	14.50 14.63 14.50	14.54	10180	10	1	0.79

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 9	8-8-T9.5-0-i-2.5-3-9.5	A B	17.0	14.3	10.25	11.79	2.5 2.5	2.5	3.3 3.5	11.0	0.375	-
	8-8-T9.5-2#3-i-2.5-3-9.5	A B	17.0	14.0	10.25	11.87	2.8 2.5	2.6	3.5 3.1	10.8	0.375	0.11
	(3@4)8-8-T9.5-0-i-2.5-3-9.5	A B C	14.0	14.0	10.25	11.98	2.5 - 2.5	2.5	3.5 3.0 3.3	4.0 4.0	0.375	-
	(3@4)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	14.0	14.3	10.25	12.47	2.5 - 2.5	2.5	3.0 3.3 3.3	4.0 4.0	0.375	0.11
	(3@5)8-8-T9.5-0-i-2.5-3-9.5	A B C	16.0	14.3	10.25	11.77	2.5 - 2.5	2.5	3.3 3.0 3.5	5.0 5.0	0.375	-
	(3@5)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	16.0	14.3	10.25	12.16	2.5 - 2.5	2.5	3.3 3.3 3.5	5.0 5.0	0.375	0.11
	(3@7)8-8-T9.5-0-i-2.5-3-9.5	A B C	19.9	14.1	10.25	12.08	2.5 - 2.5	2.5	3.1 2.9 3.2	7.0 6.9	0.375	-
	(3@7)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	20.1	14.3	10.25	12.05	2.5 - 2.5	2.5	3.3 3.0 3.3	7.0 7.1	0.375	0.11
	8-8-T9.5-0-i-2.5-3-14.5	A B	17.1	19.3	10.25	-‡	2.5 2.5	2.5	3.3 3.6	11.1	0.375	-
	(3@4)8-8-T9.5-0-i-2.5-3-14.5	A B C	14.0	19.0	10.25	13.54	2.5 - 2.5	2.5	3.3 2.8 2.8	4.0 4.0	0.375	-
	(3@4)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	14.0	19.0	10.25	13.92	2.5 - 2.5	2.5	3.0 3.0 3.3	4.0 4.0	0.375	0.11
	(3@5)8-8-T9.5-0-i-2.5-3-14.5	A B C	15.8	19.1	10.25	13.43	2.5 - 2.5	2.5	2.9 3.1 3.1	4.8 5.0	0.375	-
	(3@5)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	15.5	19.3	10.25	13.84	2.3 - 2.3	2.3	3.8 3.5 3.8	5.0 5.0	0.375	0.11
	(3@7)8-8-T9.5-0-i-2.5-3-14.5	A B C	20.0	19.1	10.25	13.02	2.5 - 2.5	2.5	3.1 3.0 2.9	7.0 7.0	0.375	-
	(3@7)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	20.0	19.1	10.25	13.28	2.5 - 2.5	2.5	3.1 2.9 3.1	7.0 7.0	0.375	0.11

‡ d_{eff} was not calculated for specimen with bar yielding

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 9	8-8-T9.5-0-i-2.5-3-9.5	A B	-	-	-	0.375	3 (1.5)	0.66	2	1.58	A6
	8-8-T9.5-2#3-i-2.5-3-9.5	A B	4	6 (4.5)	0.22	0.375	3 (1.5)	0.66	2	1.58	A6
	(3@4)8-8-T9.5-0-i-2.5-3-9.5	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@4)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	4	6 (4.5)	0.22	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@5)8-8-T9.5-0-i-2.5-3-9.5	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@5)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	4	6 (4.5)	0.22	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@7)8-8-T9.5-0-i-2.5-3-9.5	A B C	-	-	-	0.5	4.5 (2.25)	0.80	3	2.37	A7
	(3@7)8-8-T9.5-2#3-i-2.5-3-9.5	A B C	4	6 (4.5)	0.22	0.5	4.5 (2.25)	0.80	3	2.37	A7
	8-8-T9.5-0-i-2.5-3-14.5	A B	-	-	-	0.375	4 (2)	0.28	2	1.58	A6
	(3@4)8-8-T9.5-0-i-2.5-3-14.5	A B C	-	-	-	0.375	4 (2)	0.44	3	2.37	A5
	(3@4)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	4	6 (4.5)	0.22	0.375	4 (2)	0.44	3	2.37	A5
	(3@5)8-8-T9.5-0-i-2.5-3-14.5	A B C	-	-	-	0.375	3.5 (1.75)	0.44	3	2.37	A8
	(3@5)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	4	6 (4.5)	0.22	0.375	3.5 (1.75)	0.44	3	2.37	A8
	(3@7)8-8-T9.5-0-i-2.5-3-14.5	A B C	-	-	-	0.5	4.5 (2.25)	0.80	3	2.37	A8
	(3@7)8-8-T9.5-2#3-i-2.5-3-14.5	A B C	4	6 (4.5)	0.22	0.5	4.5 (2.25)	0.80	3	2.37	A8

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 9	8-8-T9.5-0-i-2.5-3-9.5	A	CB	0.168	65.0	82.3	65.0	130.5	65.2	82.5
		B		0.127	65.5	82.9	65.5			
	8-8-T9.5-2#3-i-2.5-3-9.5	A	CB	-	69.0	87.3	69.0	137.5	68.7	87.0
		B		0.103 (0.003)	68.5	86.7	68.5			
	(3@4)8-8-T9.5-0-i-2.5-3-9.5	A	CB	0.421	33.5	42.4	33.5	120.8	40.3	51.0
		B		0.232	43.2	54.7	43.2			
		C		0.356 (0.098)	44.2	55.9	44.1			
	(3@4)8-8-T9.5-2#3-i-2.5-3-9.5	A	CB	0.440	51.5	65.2	51.5	155.3	51.8	65.6
		B		0.293	54.5	69.0	54.5			
		C		0.230 (0.051)	49.3	62.4	49.3			
	(3@5)8-8-T9.5-0-i-2.5-3-9.5	A	CB	-	54.5	69.0	54.5	133.5	44.5	56.3
		B		-	27.9	35.3	27.9			
		C		0.015 (0.055)	51.0	64.6	51.0			
	(3@5)8-8-T9.5-2#3-i-2.5-3-9.5	A	CB	0.373	55.7	70.5	55.2	167.8	55.9	70.8
		B		0.430	60.6	76.7	60.6			
		C		0.342 (0.001)	52.0	65.8	52.0			
	(3@7)8-8-T9.5-0-i-2.5-3-9.5	A	CB	-	54.2	68.6	54.2	206.1	68.7	87.0
		B		0.180	66.3	83.9	66.3			
		C		0.094 (0.008)	85.6	108.4	85.6			
	(3@7)8-8-T9.5-2#3-i-2.5-3-9.5	A	CB	0.469	65.7	83.2	65.2	202.9	67.6	85.6
		B		0.124	62.6	79.2	62.6			
		C		0.145 (0.011)	75.1	95.1	75.1			
	8-8-T9.5-0-i-2.5-3-14.5	A	Y	-	117.3	148.5	117.3	237.6	118.8	150.4
		B		0.038	120.3	152.3	120.3			
	(3@4)8-8-T9.5-0-i-2.5-3-14.5	A	CB	-	80.9	102.4	80.9	229.7	76.6	97.0
		B		-	79.2	100.3	79.2			
		C		0.073	75.0	94.9	69.7			
	(3@4)8-8-T9.5-2#3-i-2.5-3-14.5	A	CB	0.122	79.5	100.6	79.5	256.3	85.4	108.1
		B		-	89.3	113.0	89.3			
		C		0.165 (0.016)	87.5	110.8	87.5			
	(3@5)8-8-T9.5-0-i-2.5-3-14.5	A	CB	0.086	87.3	110.5	87.0	279.6	93.2	118.0
		B		-	104.0	131.6	104.0			
		C		0.090 (0.031)	88.5	112.0	88.5			
	(3@5)8-8-T9.5-2#3-i-2.5-3-14.5	A	CB	0.144	93.8	118.7	93.7	315.5	105.2	133.2
		B		-	99.3	125.7	99.3			
		C		0.083	122.5	155.1	122.5			
	(3@7)8-8-T9.5-0-i-2.5-3-14.5	A	CB/BS	0.138	104.4	132.2	104.4	311.9	104.0	131.6
		B		0.166	99.2	125.6	99.2			
		C		0.130	108.3	137.1	108.3			
	(3@7)8-8-T9.5-2#3-i-2.5-3-14.5	A	CB	-	105.8	133.9	105.8	340.3	113.4	143.5
		B		-	98.7	124.9	97.9			
		C		(0.027)	136.6	172.9	136.6			

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 10	(2@9)8-12-F4.1-0-i-2.5-3-12	A B	2.0	4.1A_b	12.13 12.00	12.06	12080	57	1	0.79
	(2@9)8-12-F9.1-0-i-2.5-3-12	A B	2.0	9.1A_b	11.75 12.00	11.88	12080	57	1	0.79
	(2@9)8-12-F4.1-5#3-i-2.5-3-12	A B	2.0	4.1A_b	11.94 12.00	11.97	12080	57	1	0.79
	(2@9)8-12-F9.1-5#3-i-2.5-3-12	A B	2.0	9.1A_b	12.13 12.13	12.13	12080	57	1	0.79
	(3@4.5)8-12-F4.1-0-i-2.5-3-12	A B C	2.0	4.1A_b	12.13 12.25 12.25	12.21	12040	58	1	0.79
	(3@4.5)8-12-F9.1-0-i-2.5-3-12	A B C	2.0	9.1A_b	12.00 12.13 12.00	12.04	12040	58	1	0.79
	(3@4.5)8-12-F4.1-5#3-i-2.5-3-12	A B C	2.0	4.1A_b	12.13 12.19 12.19	12.17	12040	58	1	0.79
	(3@4.5)8-12-F9.1-5#3-i-2.5-3-12	A B C	2.0	9.1A_b	11.94 11.88 11.88	11.90	12040	58	1	0.79
	(4@3)8-12-F4.1-0-i-2.5-3-12	A B C D	2.0	4.1A_b	12.00 12.00 12.00 12.00	12.00	12040	58	1	0.79
	(4@3)8-12-F9.1-0-i-2.5-3-12	A B C D	2.0	9.1A_b	12.06 12.13 12.25 12.25	12.17	12360	61	1	0.79
	(4@3)8-12-F4.1-5#3-i-2.5-3-12	A B C D	2.0	4.1A_b	12.00 12.00 12.13 12.00	12.03	12360	61	1	0.79
	(4@3)8-12-F9.1-5#3-i-2.5-3-12	A B C D	2.0	9.1A_b	12.00 12.00 12.00 11.81	11.95	12360	61	1	0.79
Group 11	8-8-O4.5-0-i-2.5-3-9.5	A B	1.6	4.5A_b	9.13 9.25	9.19	6710	16	1	0.79
	(2@9)8-8-O4.5-0-i-2.5-3-9.5	A B	1.6	4.5A_b	9.13 8.88	9.00	6710	16	1	0.79
	(2@7)8-8-O4.5-0-i-2.5-3-9.5	A B	1.6	4.5A_b	9.38 9.13	9.25	6710	16	1	0.79
	(2@5)8-8-O4.5-0-i-2.5-3-9.5	A B	1.6	4.5A_b	9.13 8.88	9.00	6710	16	1	0.79

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 10	(2@9)8-12-F4.1-0-i-2.5-3-12	A B	15.0	16.1	10.25	11.83	2.5 2.5	2.5	2.9 3.1	9.0	0.375	-
	(2@9)8-12-F9.1-0-i-2.5-3-12	A B	14.9	16.0	10.25	11.78	2.5 2.5	2.5	3.3 3.0	8.9	0.375	-
	(2@9)8-12-F4.1-5#3-i-2.5-3-12	A B	14.9	16.1	10.25	12.49	2.5 2.4	2.5	3.2 3.1	9.0	0.375	0.11
	(2@9)8-12-F9.1-5#3-i-2.5-3-12	A B	14.9	17.7	10.25	-‡	2.4 2.5	2.4	4.5 4.5	9.0	0.375	0.11
	(3@4.5)8-12-F4.1-0-i-2.5-3-12	A B C	14.8	16.1	10.25	12.51	2.5 - 2.5	2.5	2.9 2.8 2.8	4.5 4.3	0.375	-
	(3@4.5)8-12-F9.1-0-i-2.5-3-12	A B C	14.8	16.1	10.25	12.52	2.4 - 2.4	2.4	3.1 2.9 3.1	4.5 4.5	0.375	-
	(3@4.5)8-12-F4.1-5#3-i-2.5-3-12	A B C	15.2	16.1	10.25	12.89	2.6 - 2.6	2.6	2.9 2.9 2.9	4.4 4.5	0.375	0.11
	(3@4.5)8-12-F9.1-5#3-i-2.5-3-12	A B C	15.0	16.0	10.25	13.51	2.5 - 2.5	2.5	3.1 3.1 3.1	4.5 4.5	0.375	0.11
	(4@3)8-12-F4.1-0-i-2.5-3-12	A B C D	14.9	16.0	10.25	12.23	2.4 - - 2.5	2.4	3.0 3.0 3.0 3.0	3.0 3.0 3.0	0.375	-
	(4@3)8-12-F9.1-0-i-2.5-3-12	A B C D	15.0	16.2	10.25	12.22	2.5 - - 2.5	2.5	3.1 3.0 2.9 2.9	3.0 3.0 3.0	0.375	-
	(4@3)8-12-F4.1-5#3-i-2.5-3-12	A B C D	15.1	16.2	10.25	12.76	2.4 - - 2.5	2.5	3.2 3.2 3.0 3.2	3.1 3.0 3.0	0.375	0.11
	(4@3)8-12-F9.1-5#3-i-2.5-3-12	A B C D	14.9	16.0	10.25	13.68	2.4 - - 2.5	2.5	3.0 3.0 3.0 3.2	3.0 3.0 3.0	0.375	0.11
Group 11	8-8-O4.5-0-i-2.5-3-9.5	A B	17.3	14.1	10.25	11.93	2.8 2.4	2.6	3.3 3.2	11.1	0.375	-
	(2@9)8-8-O4.5-0-i-2.5-3-9.5	A B	15.3	14.1	10.25	12.17	2.6 2.5	2.6	3.3 3.6	9.1	0.375	-
	(2@7)8-8-O4.5-0-i-2.5-3-9.5	A B	13.1	14.1	10.25	12.31	2.5 2.6	2.6	3.1 3.3	7.0	0.375	-
	(2@5)8-8-O4.5-0-i-2.5-3-9.5	A B	11.3	14.2	10.25	12.53	2.5 2.5	2.5	3.4 3.7	5.3	0.375	-

‡ d_{eff} was not calculated for specimen with bar yielding

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 10	(2@9)8-12-F4.1-0-i-2.5-3-12	A B	-	-	-	0.5	3 (1.5)	1.20	2	1.58	A5
	(2@9)8-12-F9.1-0-i-2.5-3-12	A B	-	-	-	0.5	3 (1.5)	1.20	2	1.58	A5
	(2@9)8-12-F4.1-5#3-i-2.5-3-12	A B	10	3 (1.5)	0.66	0.5	3 (1.5)	1.20	2	1.58	A5
	(2@9)8-12-F9.1-5#3-i-2.5-3-12	A B	10	3 (1.5)	0.66	0.5	3 (1.5)	0.76	2	1.58	A5
	(3@4.5)8-12-F4.1-0-i-2.5-3-12	A B C	-	-	-	0.5	3 (1.5)	1.20	3	2.37	A5
	(3@4.5)8-12-F9.1-0-i-2.5-3-12	A B C	-	-	-	0.5	3 (1.5)	1.20	3	2.37	A5
	(3@4.5)8-12-F4.1-5#3-i-2.5-3-12	A B C	10	3 (1.5)	0.66	0.5	3 (1.5)	1.20	3	2.37	A5
	(3@4.5)8-12-F9.1-5#3-i-2.5-3-12	A B C	10	3 (1.5)	0.66	0.5	3 (1.5)	1.20	3	2.37	A5
	(4@3)8-12-F4.1-0-i-2.5-3-12	A B C D	-	-	-	0.5	3 (1.5)	1.20	4	3.16	A5
	(4@3)8-12-F9.1-0-i-2.5-3-12	A B C D	-	-	-	0.5	3 (1.5)	1.20	4	3.16	A5
	(4@3)8-12-F4.1-5#3-i-2.5-3-12	A B C D	10	3 (1.5)	0.66	0.5	3 (1.5)	1.20	4	3.16	A5
	(4@3)8-12-F9.1-5#3-i-2.5-3-12	A B C D	10	3 (1.5)	0.66	0.5	3 (1.5)	1.20	4	3.16	A5
Group 11	8-8-O4.5-0-i-2.5-3-9.5	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A4
	(2@9)8-8-O4.5-0-i-2.5-3-9.5	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A4
	(2@7)8-8-O4.5-0-i-2.5-3-9.5	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A4
	(2@5)8-8-O4.5-0-i-2.5-3-9.5	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A4

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 10	(2@9)8-12-F4.1-0-i-2.5-3-12	A	CB/FP	-	79.8	101.0	79.8	158.1	79.1	100.1
		B		-	78.3	99.1	78.3			
	(2@9)8-12-F9.1-0-i-2.5-3-12	A	CB/BS	0.048	76.1	96.3	76.1	153.0	76.5	96.8
		B		-	76.9	97.3	76.9			
	(2@9)8-12-F4.1-5#3-i-2.5-3-12	A	SB/FP	0.126	112.5‡	142.4‡	112.5	223.8	111.9	141.6
		B		0.126	111.3	140.9	111.3			
	(2@9)8-12-F9.1-5#3-i-2.5-3-12	A	Y	0.200	125.2	158.5	125.2	242.3	121.2	153.4
		B		0.025	117.1	148.2	117.1			
	(3@4.5)8-12-F4.1-0-i-2.5-3-12	A	CB	0.133	79.1	100.1	79.1	225.7	75.2	95.2
		B		0.037	75.8	95.9	75.8			
		C		0.089	70.7	89.5	70.7			
	(3@4.5)8-12-F9.1-0-i-2.5-3-12	A	CB	(0.046)	77.8	98.5	77.8	226.2	75.4	95.4
		B		-	63.3	80.1	63.3			
		C		0.117	85.1	107.7	85.1			
	(3@4.5)8-12-F4.1-5#3-i-2.5-3-12	A	CB	0.170	83.8	106.1	83.8	263.1	87.7	111.0
		B		0.094	86.0	108.9	86.0			
		C		0.169	93.2	118.0	93.2			
	(3@4.5)8-12-F9.1-5#3-i-2.5-3-12	A	CB	0.250	108.1	136.8	108.1	325.7	108.6	137.4
		B		0.096	110.7	140.1	110.7			
		C		0.234	106.9	135.3	106.9			
	(4@3)8-12-F4.1-0-i-2.5-3-12	A	CB	-	41.7	52.8	41.7	197.2	49.3	62.4
		B		-	49.5	62.7	49.5			
		C		0.135	66.8	84.6	66.8			
		D		0.032	39.4	49.9	39.4			
	(4@3)8-12-F9.1-0-i-2.5-3-12	A	CB	-	49.2	62.3	49.2	201.3	50.3	63.7
		B		-	45.7	57.8	45.7			
		C		-	53.2	67.3	53.2			
		D		-	53.1	67.2	53.1			
	(4@3)8-12-F4.1-5#3-i-2.5-3-12	A	CB	0.030	73.8	93.4	73.8	256.7	64.2	81.2
		B		-	63.3	80.1	63.3			
		C		0.101	48.2	61.0	48.2			
		D		0.093	71.5	90.5	71.5			
	(4@3)8-12-F9.1-5#3-i-2.5-3-12	A	CB	-	85.2	107.8	85.2	351.3	87.8	111.1
		B		-	72.8	92.2	72.8			
		C		-	111.1	140.6	111.1			
		D		-	82.1	103.9	82.1			
Group 11	8-8-O4.5-0-i-2.5-3-9.5	A	CB/FP	0.002	61.9	78.4	61.8	116.7	58.4	73.9
		B		0.002	54.9	69.5	54.9			
	(2@9)8-8-O4.5-0-i-2.5-3-9.5	A	CB	0.014	57.5	72.8	57.5	117.6	58.8	74.4
		B		0.019	60.1	76.1	60.1			
	(2@7)8-8-O4.5-0-i-2.5-3-9.5	A	CB	0.010	57.2	72.4	57.2	109.0	54.5	69.0
		B		0.030	51.8	65.6	51.8			
	(2@5)8-8-O4.5-0-i-2.5-3-9.5	A	CB	0.035	45.7	57.8	45.7	102.4	51.2	64.8
		B		0.041	56.7	71.8	56.7			

‡ No anchorage failure on the bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 11	(2@3)8-8-O4.5-0-i-2.5-3-9.5	A B	1.6	4.5A_b	9.13 8.88	9.00	6710	16	1	0.79
	(2@9)8-8-T4.0-0-i-2.5-3-9.5	A B	1.9	4.0A_b	9.25 9.50	9.38	6790	17	1	0.79
	(2@9)8-8-T4.0-5#3-i-2.5-3-9.5	A B	1.9	4.0A_b	9.50 9.50	9.50	6790	17	1	0.79
	(3@4.5)8-8-T4.0-0-i-2.5-3-9.5	A B C	1.9	4.0A_b	9.25 9.50 9.25	9.33	6790	17	1	0.79
	(3@4.5)8-8-T4.0-5#3-i-2.5-3-9.5	A B C	1.9	4.0A_b	9.13 9.25 9.13	9.17	6650	20	1	0.79
	(4@3)8-8-T4.0-0-i-2.5-3-9.5	A B C D	1.9	4.0A_b	9.63 9.63 9.25 9.38	9.47	6650	20	1	0.79
	(4@3)8-8-T4.0-5#3-i-2.5-3-9.5	A B C D	1.9	4.0A_b	9.75 9.63 9.88 9.38	9.66	6650	20	1	0.79
	(3@3)8-8-T4.0-0-i-2.5-3-9.5	A B C	1.9	4.0A_b	9.25 9.63 9.50	9.46	6790	17	1	0.79
	(3@3)8-8-T4.0-5#3-i-2.5-3-9.5	A B C	1.9	4.0A_b	9.25 9.38 9.38	9.33	6650	20	1	0.79
Group 12	8-5-F4.1-0-i-2.5-7-6	A B	2.0	4.1A_b	6.06 6.13	6.09	4930	14	1	0.79
	8-5-F4.1-5#3-i-2.5-7-6	A B	2.0	4.1A_b	6.25 6.25	6.25	4930	14	1	0.79
	(3@3)8-5-F4.1-0-i-2.5-7-6	A B C	2.0	4.1A_b	6.06 6.25 6.25	6.19	4930	14	1	0.79
	(3@3)8-5-F4.1-5#3-i-2.5-7-6	A B C	2.0	4.1A_b	6.00 6.00 6.00	6.00	4930	14	1	0.79
	(3@5)8-5-F4.1-0-i-2.5-7-6	A B C	2.0	4.1A_b	6.50 6.25 6.25	6.33	4930	14	1	0.79
	(3@5)8-5-F4.1-5#3-i-2.5-7-6	A B C	2.0	4.1A_b	6.25 6.13 6.50	6.29	4930	14	1	0.79
	(3@7)8-5-F4.1-0-i-2.5-7-6	A B C	2.0	4.1A_b	6.25 6.25 6.25	6.25	4940	15	1	0.79

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 11	(2@3)8-8-O4.5-0-i-2.5-3-9.5	A B	9.1	14.1	10.25	12.85	2.4 2.6	2.5	3.4 3.6	3.1	0.375	-
	(2@9)8-8-T4.0-0-i-2.5-3-9.5	A B	15.1	14.1	10.25	12.26	2.5 2.5	2.5	3.4 3.1	9.1	0.375	-
	(2@9)8-8-T4.0-5#3-i-2.5-3-9.5	A B	15.1	14.0	10.25	12.74	2.5 2.5	2.5	3.0 3.0	9.1	0.375	0.11
	(3@4.5)8-8-T4.0-0-i-2.5-3-9.5	A B C	15.1	14.1	10.25	12.23	2.6 - 2.5	2.6	3.4 3.1 3.4	4.5 4.5	0.375	-
	(3@4.5)8-8-T4.0-5#3-i-2.5-3-9.5	A B C	15.3	14.2	10.25	13.33	2.4 - 2.5	2.4	3.6 3.4 3.6	4.8 4.6	0.375	0.11
	(4@3)8-8-T4.0-0-i-2.5-3-9.5	A B C D	14.8	14.2	10.25	11.97	2.4 - - 2.5	2.4	3.1 3.1 3.4 3.3	3.0 2.9 3.0	0.375	-
	(4@3)8-8-T4.0-5#3-i-2.5-3-9.5	A B C D	15.3	14.1	10.25	13.45	2.6 - - 2.5	2.6	2.9 3.0 2.8 3.3	3.0 3.1 3.0	0.375	0.11
	(3@3)8-8-T4.0-0-i-2.5-3-9.5	A B C	12.3	14.0	10.25	12.65	2.5 - 2.5	2.5	3.3 2.9 3.0	3.1 3.1	0.375	-
	(3@3)8-8-T4.0-5#3-i-2.5-3-9.5	A B C	12.1	14.1	10.25	13.73	2.6 - 2.4	2.5	3.3 3.2 3.2	3.0 3.1	0.375	0.11
Group 12	8-5-F4.1-0-i-2.5-7-6	A B	17.3	14.2	10.25	11.25	2.5 2.8	2.6	7.2 7.1	11.0	0.375	-
	8-5-F4.1-5#3-i-2.5-7-6	A B	17.1	14.0	10.25	12.02	2.5 2.6	2.6	6.8 6.8	11.0	0.375	0.11
	(3@3)8-5-F4.1-0-i-2.5-7-6	A B C	12.6	13.7	10.25	11.78	2.8 - 2.5	2.6	6.6 6.4 6.4	3.3 3.1	0.375	-
	(3@3)8-5-F4.1-5#3-i-2.5-7-6	A B C	12.5	14.0	10.25	12.63	2.5 - 2.6	2.6	7.0 7.0 7.0	3.3 3.1	0.375	0.11
	(3@5)8-5-F4.1-0-i-2.5-7-6	A B C	16.9	14.2	10.25	11.58	2.8 - 2.8	2.8	6.7 6.9 6.9	5.1 5.3	0.375	-
	(3@5)8-5-F4.1-5#3-i-2.5-7-6	A B C	16.8	14.3	10.25	12.34	2.8 - 2.8	2.8	7.0 7.1 6.8	5.3 5.0	0.375	0.11
	(3@7)8-5-F4.1-0-i-2.5-7-6	A B C	20.5	14.3	10.25	11.45	2.8 - 2.6	2.7	7.0 7.0 7.0	7.1 7.0	0.375	-

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 11	(2@3)8-8-O4.5-0-i-2.5-3-9.5	A B	-	-	-	0.375	4 (2)	0.44	2	1.58	A4
	(2@9)8-8-T4.0-0-i-2.5-3-9.5	A B	-	-	-	0.5	4 (2)	0.80	2	1.58	A9
	(2@9)8-8-T4.0-5#3-i-2.5-3-9.5	A B	10	3 (1.5)	0.66	0.5	4 (2)	0.80	2	1.58	A5
	(3@4.5)8-8-T4.0-0-i-2.5-3-9.5	A B C	-	-	-	0.5	4 (2)	0.80	3	2.37	A9
	(3@4.5)8-8-T4.0-5#3-i-2.5-3-9.5	A B C	10	3 (1.5)	0.66	0.5	4 (2)	0.80	3	2.37	A5
	(4@3)8-8-T4.0-0-i-2.5-3-9.5	A B C D	-	-	-	0.5	4 (2)	0.80	4	3.16	A9
	(4@3)8-8-T4.0-5#3-i-2.5-3-9.5	A B C D	10	3 (1.5)	0.66	0.5	4 (2)	0.80	4	3.16	A5
	(3@3)8-8-T4.0-0-i-2.5-3-9.5	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@3)8-8-T4.0-5#3-i-2.5-3-9.5	A B C	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	3	2.37	A5
Group 12	8-5-F4.1-0-i-2.5-7-6	A B	-	-	-	0.375	3 (1.5)	0.66	2	1.58	A4
	8-5-F4.1-5#3-i-2.5-7-6	A B	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	2	1.58	A4
	(3@3)8-5-F4.1-0-i-2.5-7-6	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A4
	(3@3)8-5-F4.1-5#3-i-2.5-7-6	A B C	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@5)8-5-F4.1-0-i-2.5-7-6	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@5)8-5-F4.1-5#3-i-2.5-7-6	A B C	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@7)8-5-F4.1-0-i-2.5-7-6	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A8

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 11	(2@3)8-8-O4.5-0-i-2.5-3-9.5	A	CB	0.037	51.9	65.7	51.9	95.5	47.7	60.4
		B		0.021	43.6	55.2	43.6			
	(2@9)8-8-T4.0-0-i-2.5-3-9.5	A	CB	0.015	65.0	82.3	65.0	123.7	61.8	78.2
		B		0.016	58.7	74.3	58.7			
	(2@9)8-8-T4.0-5#3-i-2.5-3-9.5	A	SB/FP	0.078	70.7	89.5	70.7	153.3	76.7	97.1
		B		0.035	87.5	110.8	82.6			
	(3@4.5)8-8-T4.0-0-i-2.5-3-9.5	A	CB	0.013	43.9	55.6	43.9	122.1	40.7	51.5
		B		0.013	27.9	35.3	27.9			
		C		0.013	50.3	63.7	50.3			
	(3@4.5)8-8-T4.0-5#3-i-2.5-3-9.5	A	CB/FP	0.015	56.5	71.5	55.3	187.4	62.5	79.1
		B		0.558	68.6	86.8	65.8			
		C		0.003	66.4	84.1	66.3			
	(4@3)8-8-T4.0-0-i-2.5-3-9.5	A	CB	-	25.2	31.9	25.2	104.6	26.2	33.1
		B		-	31.2	39.5	31.2			
		C		-	31.7	40.1	31.7			
		D		0.005	16.6	21.0	16.5			
	(4@3)8-8-T4.0-5#3-i-2.5-3-9.5	A	CB	0.005	57.7	73.0	57.7	194.6	48.6	61.5
		B		-	30.1	38.1	30.1			
		C		-	52.3	66.2	52.3			
		D		0.015	54.4	68.9	54.4			
	(3@3)8-8-T4.0-0-i-2.5-3-9.5	A	CB	0.014	39.9	50.5	39.9	118.1	39.4	49.8
		B		0.016	44.3	56.1	44.3			
		C		0.014	33.9	42.9	33.9			
	(3@3)8-8-T4.0-5#3-i-2.5-3-9.5	A	CB	0.003	56.9	72.0	56.8	169.6	56.5	71.6
		B		-	63.6	80.5	63.6			
		C		0.007	49.3	62.4	49.2			
Group 12	8-5-F4.1-0-i-2.5-7-6	A	CB	0.005	30.2	38.2	27.7	57.3	28.7	36.3
		B		0.027	29.7	37.6	29.7			
	8-5-F4.1-5#3-i-2.5-7-6	A	CB	0.027	51.6	65.3	48.8	101.3	50.7	64.1
		B		0.023	52.7	66.7	52.5			
	(3@3)8-5-F4.1-0-i-2.5-7-6	A	CB	-	15.5	19.6	14.9	61.8	20.6	26.1
		B		-	24.3	30.8	24.3			
		C		-	22.7	28.7	22.7			
	(3@3)8-5-F4.1-5#3-i-2.5-7-6	A	CB	-	32.2	40.8	32.2	96.3	32.1	40.6
		B		-	30.8	39.0	30.8			
		C		-	33.3	42.2	33.3			
	(3@5)8-5-F4.1-0-i-2.5-7-6	A	CB	0.026	24.1	30.5	24.0	71.8	23.9	30.3
		B		-	23.8	30.1	23.3			
		C		0.002	24.5	31.0	24.5			
	(3@5)8-5-F4.1-5#3-i-2.5-7-6	A	CB	0.007	31.3	39.6	30.9	112.6	37.5	47.5
		B		0.014	38.3	48.5	38.3			
		C		0.014	43.8	55.5	43.4			
	(3@7)8-5-F4.1-0-i-2.5-7-6	A	CB	0.001	31.1	39.4	31.1	81.2	27.1	34.3
		B		-	19.1	24.2	19.0			
		C		0.013	31.1	39.4	31.1			

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 12	(3@7)8-5-F4.1-5#3-i-2.5-7-6	A B C	2.0	4.1A_b	6.00 6.19 6.13	6.10	4940	15	1	0.79
	8-5-F9.1-0-i-2.5-7-6	A B	2.0	9.1A_b	6.13 6.13	6.13	4940	15	1	0.79
	8-5-F9.1-5#3-i-2.5-7-6	A B	2.0	9.1A_b	6.19 6.13	6.16	4940	15	1	0.79
	(3@5.5)8-5-F9.1-0-i-2.5-7-6	A B C	2.0	9.1A_b	6.25 6.13 6.25	6.21	5160	16	1	0.79
	(3@5.5)8-5-F9.1-5#3-i-2.5-7-6	A B C	2.0	9.1A_b	6.13 6.25 6.38	6.25	5160	16	1	0.79
	(4@3.7)8-5-T9.5-0-i-2.5-6.5-6	A B C D	1.4	9.5A_b	6.19 6.13 6.19 6.00	6.13	5160	16	1	0.79
	(4@3.7)8-5-F9.1-5#3-i-2.5-7-6	A B C D	2.0	9.1A_b	6.00 6.00 6.00 6.13	6.03	5160	16	1	0.79
Group 13	5-5-F4.0-0-i-2.5-5-4	A B	2.2	4.0A_b	4.00 4.13	4.06	4810	8	0.625	0.31
	5-5-F13.1-0-i-2.5-5-4	A B	2.2	13.1A_b	4.25 4.56	4.41	4810	8	0.625	0.31
	5-5-F4.0-2#3-i-2.5-5-4	A B	2.2	4.0A_b	3.88 3.75	3.81	4810	8	0.625	0.31
	5-5-F13.1-2#3-i-2.5-5-4	A B	2.2	13.1A_b	4.25 3.94	4.09	4810	8	0.625	0.31
	5-5-F4.0-5#3-i-2.5-5-4	A B	2.2	4.0A_b	3.94 4.38	4.16	4810	8	0.625	0.31
	5-5-F13.1-5#3-i-2.5-5-4	A B	2.2	13.1A_b	4.13 4.25	4.19	4690	7	0.625	0.31
	5-5-F4.0-0-i-2.5-3-6	A B	2.2	4.0A_b	6.00 6.00	6.00	4690	7	0.625	0.31
	5-5-F13.1-0-i-2.5-3-6	A B	2.2	13.1A_b	6.13 6.31	6.22	4690	7	0.625	0.31
	5-5-F4.0-2#3-i-2.5-3-6	A B	2.2	4.0A_b	6.00 6.00	6.00	4690	7	0.625	0.31
	5-5-F13.1-2#3-i-2.5-3-6	A B	2.2	13.1A_b	5.88 6.00	5.94	4690	7	0.625	0.31
	5-5-F4.0-5#3-i-2.5-3-6	A B	2.2	4.0A_b	6.00 6.13	6.06	4690	7	0.625	0.31

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 12	(3@7)8-5-F4.1-5#3-i-2.5-7-6	A B C	20.5	14.1	10.25	12.13	2.6 - 2.8	2.7	7.1 6.9 7.0	7.1 7.0	0.375	0.11
	8-5-F9.1-0-i-2.5-7-6	A B	17.3	14.2	10.25	11.42	2.8 2.8	2.8	7.0 7.0	10.8	0.375	-
	8-5-F9.1-5#3-i-2.5-7-6	A B	17.0	14.1	10.25	12.13	2.5 2.5	2.5	6.9 7.0	11.0	0.375	0.11
	(3@5.5)8-5-F9.1-0-i-2.5-7-6	A B C	17.3	14.4	10.25	11.42	2.5 - 2.8	2.6	7.1 7.3 7.1	5.5 5.5	0.375	-
	(3@5.5)8-5-F9.1-5#3-i-2.5-7-6	A B C	17.3	14.4	10.25	12.44	2.5 - 2.8	2.6	7.3 7.1 7.0	5.5 5.5	0.375	0.11
	(4@3.7)8-5-T9.5-0-i-2.5-6.5-6	A B C D	17.0	14.2	10.25	11.72	2.8 - - 2.5	2.6	6.5 6.6 6.5 6.7	3.5 3.6 3.6	0.375	-
	(4@3.7)8-5-F9.1-5#3-i-2.5-7-6	A B C D	17.4	14.3	10.25	12.39	2.5 - - 2.6	2.6	7.3 7.3 7.3 7.1	3.8 3.8 3.8	0.375	0.11
Group 13	5-5-F4.0-0-i-2.5-5-4	A B	12.9	9.8	5.25	6.39	2.5 2.5	2.5	5.3 5.1	7.3	-	-
	5-5-F13.1-0-i-2.5-5-4	A B	13.1	9.6	5.25	6.56	2.5 2.5	2.5	4.8 4.5	7.5	-	-
	5-5-F4.0-2#3-i-2.5-5-4	A B	13.0	9.6	5.25	6.16	2.5 2.5	2.5	5.3 5.4	7.4	0.375	0.11
	5-5-F13.1-2#3-i-2.5-5-4	A B	13.1	9.8	5.25	6.59	2.6 2.6	2.6	5.1 5.4	7.3	0.375	0.11
	5-5-F4.0-5#3-i-2.5-5-4	A B	13.1	9.8	5.25	6.48	2.6 2.5	2.6	5.3 4.9	7.4	0.375	0.11
	5-5-F13.1-5#3-i-2.5-5-4	A B	13.0	9.8	5.25	6.92	2.5 2.5	2.5	5.1 5.0	7.4	0.375	0.11
	5-5-F4.0-0-i-2.5-3-6	A B	13.1	9.8	5.25	6.80	2.5 2.6	2.6	3.3 3.3	7.3	-	-
	5-5-F13.1-0-i-2.5-3-6	A B	13.3	9.7	5.25	6.92	2.5 2.6	2.6	3.1 2.9	7.5	-	-
	5-5-F4.0-2#3-i-2.5-3-6	A B	13.1	9.7	5.25	7.04	2.6 2.5	2.6	3.2 3.2	7.4	0.375	0.11
	5-5-F13.1-2#3-i-2.5-3-6	A B	12.9	9.7	5.25	7.45	2.5 2.6	2.5	3.3 3.2	7.3	0.375	0.11
	5-5-F4.0-5#3-i-2.5-3-6	A B	13.1	9.7	5.25	7.31	2.5 2.6	2.6	3.2 3.1	7.4	0.375	0.11

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 12	(3@7)8-5-F4.1-5#3-i-2.5-7-6	A B C	10	3 (1.5)	0.66	0.5	4 (2)	0.80	3	2.37	A8
	8-5-F9.1-0-i-2.5-7-6	A B	-	-	-	0.375	3 (1.5)	0.66	2	1.58	A4
	8-5-F9.1-5#3-i-2.5-7-6	A B	10	3 (1.5)	0.66	0.375	3 (1.5)	0.66	2	1.58	A9
	(3@5.5)8-5-F9.1-0-i-2.5-7-6	A B C	-	-	-	0.375	3 (1.5)	0.66	3	2.37	A5
	(3@5.5)8-5-F9.1-5#3-i-2.5-7-6	A B C	10	3 (1.5)	0.66	0.5	4 (2)	0.80	3	2.37	A5
	(4@3.7)8-5-T9.5-0-i-2.5-6.5-6	A B C D	-	-	-	0.375	3 (1.5)	0.66	4	3.16	A5
	(4@3.7)8-5-F9.1-5#3-i-2.5-7-6	A B C D	10	3 (1.5)	0.66	0.5	3 (1.5)	1.20	4	3.16	A5
Group 13	5-5-F4.0-0-i-2.5-5-4	A B	-	-	-	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F13.1-0-i-2.5-5-4	A B	-	-	-	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F4.0-2#3-i-2.5-5-4	A B	4	3.5 (2.625)	0.22	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F13.1-2#3-i-2.5-5-4	A B	4	3.5 (2.625)	0.22	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F4.0-5#3-i-2.5-5-4	A B	10	1.75 (0.875)	0.66	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F13.1-5#3-i-2.5-5-4	A B	10	1.75 (0.875)	0.66	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F4.0-0-i-2.5-3-6	A B	-	-	-	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F13.1-0-i-2.5-3-6	A B	-	-	-	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F4.0-2#3-i-2.5-3-6	A B	4	3.5 (2.625)	0.22	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F13.1-2#3-i-2.5-3-6	A B	4	3.5 (2.625)	0.22	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-5-F4.0-5#3-i-2.5-3-6	A B	10	1.75 (0.875)	0.66	0.375	3.5 (1.75)	0.22	2	0.62	A4

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 12	(3@7)8-5-F4.1-5#3-i-2.5-7-6	A	CB	-	44.1	55.8	44.1	126.8	42.3	53.5
		B		-	35.2	44.6	35.2			
		C		-	47.5	60.1	47.5			
	8-5-F9.1-0-i-2.5-7-6	A	CB	0.001	32.4	41.0	32.0	66.8	33.4	42.3
		B		-	34.8	44.1	34.8			
	8-5-F9.1-5#3-i-2.5-7-6	A	CB	0.017	53.4	67.6	53.4	107.6	53.8	68.1
		B		0.033	54.3	68.7	54.2			
	(3@5.5)8-5-F9.1-0-i-2.5-7-6	A	CB	0.014	28.6	36.2	28.6	68.9	23.0	29.1
		B		-	13.9	17.6	13.9			
		C		0.015	26.4	33.4	26.4			
	(3@5.5)8-5-F9.1-5#3-i-2.5-7-6	A	CB	0.025	40.5	51.3	39.9	129.4	43.1	54.6
		B		-	46.5	58.9	46.5			
		C		0.022	43.0	54.4	43.0			
	(4@3.7)8-5-T9.5-0-i-2.5-6.5-6	A	CB	0.001	25.9	32.8	25.9	86.9	21.7	27.5
		B		0.016	14.6	18.5	14.6			
		C		-	17.8	22.5	17.8			
		D		0.024	28.8	36.5	28.6			
	(4@3.7)8-5-F9.1-5#3-i-2.5-7-6	A	CB	-	39.5	50.0	39.5	126.5	31.6	40.0
		B		-	31.5	39.9	31.5			
		C		-	20.4	25.8	20.4			
		D		0.023	35.1	44.4	35.1			
Group 13	5-5-F4.0-0-i-2.5-5-4	A	CB	-	25.9	83.5	25.9	49.1	24.5	79.0
		B		-	23.1	74.5	23.1			
	5-5-F13.1-0-i-2.5-5-4	A	CB	-	26.6	85.8	26.5	56.4	28.2	91.0
		B		-	30.2	97.4	29.9			
	5-5-F4.0-2#3-i-2.5-5-4	A	CB	-	20.1	64.8	20.1	39.3	19.7	63.5
		B		-	19.2	61.9	19.2			
	5-5-F13.1-2#3-i-2.5-5-4	A	CB	-	28.6	92.3	27.9	57.7	28.9	93.2
		B		-	30.1	97.1	29.8			
	5-5-F4.0-5#3-i-2.5-5-4	A	CB	-	27.0	87.1	27.0	53.0	26.5	85.5
		B		-	26.1‡	84.2‡	26.0			
	5-5-F13.1-5#3-i-2.5-5-4	A	CB	-	35.5	114.5	35.5	70.4	35.2	113.5
		B		-	34.8	112.3	34.8			
	5-5-F4.0-0-i-2.5-3-6	A	SB	-	34.6‡	111.6‡	32.9	65.5	32.7	105.5
		B		-	33.0	106.5	32.6			
	5-5-F13.1-0-i-2.5-3-6	A	SB/FP	-	33.2‡	107.1‡	33.1	70.6	35.3	113.9
		B		-	37.6	121.3	37.5			
	5-5-F4.0-2#3-i-2.5-3-6	A	SB/FP	-	40.0	129.0	35.5	75.7	37.9	122.3
		B		-	40.3	130.0	40.3			
	5-5-F13.1-2#3-i-2.5-3-6	A	SB/FP	-	46.3‡	149.4‡	46.3	92.8	46.4	149.7
		B		-	46.6	150.3	46.5			
	5-5-F4.0-5#3-i-2.5-3-6	A	SB/FP	-	42.4	136.8	42.4	86.9	43.5	140.3
		B		-	44.6	143.9	44.6			

‡ No anchorage failure on the bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 14	5-12-F4.0-0-i-2.5-5-4	A B	2.2	4.0A_b	4.13 4.00	4.06	11030	35	0.625	0.31
	5-12-F13.1-0-i-2.5-5-4	A B	2.2	13.1A_b	4.13 4.13	4.13	11030	35	0.625	0.31
	5-12-F4.0-2#3-i-2.5-5-4	A B	2.2	4.0A_b	4.13 4.13	4.13	11030	35	0.625	0.31
	5-12-F13.1-2#3-i-2.5-5-4	A B	2.2	13.1A_b	4.06 4.13	4.09	11030	35	0.625	0.31
	5-12-F4.0-5#3-i-2.5-5-4	A B	2.2	4.0A_b	4.19 4.25	4.22	11030	35	0.625	0.31
	5-12-F13.1-5#3-i-2.5-5-4	A B	2.2	13.1A_b	4.13 4.13	4.13	11030	35	0.625	0.31
	5-12-F4.0-0-i-2.5-3-6	A B	2.2	4.0A_b	6.00 6.00	6.00	11030	36	0.625	0.31
	5-12-F13.1-0-i-2.5-3-6	A B	2.2	13.1A_b	6.00 6.06	6.03	11030	36	0.625	0.31
	(3@5.9)5-12-F4.0-0-i-2.5-4-5	A B C	2.2	4.0A_b	5.06 5.06 5.00	5.04	11030	36	0.625	0.31
	(3@5.9)5-12-F4.0-2#3-i-2.5-4-5	A B C	2.2	4.0A_b	5.13 5.13 5.19	5.15	11030	36	0.625	0.31
	(3@5.9)5-12-F4.0-5#3-i-2.5-4-5	A B C	2.2	4.0A_b	5.19 4.88 5.00	5.02	11030	36	0.625	0.31
	(4@3.9)5-12-F4.0-0-i-2.5-4-5	A B C D	2.2	4.0A_b	5.19 5.13 5.25 5.19	5.19	11030	39	0.625	0.31
	(4@3.9)5-12-F4.0-2#3-i-2.5-4-5	A B C D	2.2	4.0A_b	5.00 5.00 5.13 5.00	5.03	11030	39	0.625	0.31
	(4@3.9)5-12-F4.0-5#3-i-2.5-4-5	A B C D	2.2	4.0A_b	5.25 5.13 5.19 5.19	5.19	11030	39	0.625	0.31
Group 15	11-5a-F3.8-0-i-2.5-3-17	A B	2.0	3.8A_b	16.38 16.75	16.56	4050	36	1.41	1.56
	11-5a-F3.8-2#3-i-2.5-3-17	A B	2.0	3.8A_b	17.44 17.44	17.44	4050	36	1.41	1.56
	11-5a-F3.8-6#3-i-2.5-3-17	A B	2.0	3.8A_b	16.75 16.69	16.72	4050	36	1.41	1.56

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 14	5-12-F4.0-0-i-2.5-5-4	A B	13.1	9.8	5.25	5.96	2.6 2.6	2.6	5.1 5.3	7.3	-	-
	5-12-F13.1-0-i-2.5-5-4	A B	13.0	9.6	5.25	6.04	2.5 2.5	2.5	4.9 4.9	7.4	-	-
	5-12-F4.0-2#3-i-2.5-5-4	A B	13.1	9.6	5.25	6.08	2.8 2.5	2.6	5.0 5.0	7.3	0.375	0.11
	5-12-F13.1-2#3-i-2.5-5-4	A B	13.1	9.7	5.25	6.17	2.3 2.9	2.6	5.2 5.1	7.4	0.375	0.11
	5-12-F4.0-5#3-i-2.5-5-4	A B	13.1	9.5	5.25	6.23	2.5 2.6	2.6	4.8 4.8	7.4	0.375	0.11
	5-12-F13.1-5#3-i-2.5-5-4	A B	13.1	9.7	5.25	6.27	2.5 2.6	2.5	5.0 5.0	7.4	0.375	0.11
	5-12-F4.0-0-i-2.5-3-6	A B	13.1	9.6	5.25	6.30	2.6 2.5	2.6	3.1 3.1	7.4	-	-
	5-12-F13.1-0-i-2.5-3-6	A B	13.0	9.7	5.25	6.36	2.5 2.6	2.6	3.2 3.1	7.3	-	-
	(3@5.9)5-12-F4.0-0-i-2.5-4-5	A B C	13.1	9.8	5.25	6.31	2.5 - 2.5	2.5	4.2 4.2 4.3	3.8 3.8	-	-
	(3@5.9)5-12-F4.0-2#3-i-2.5-4-5	A B C	13.1	9.7	5.25	6.58	2.5 - 2.5	2.5	4.1 4.1 4.0	3.8 3.8	0.375	0.11
	(3@5.9)5-12-F4.0-5#3-i-2.5-4-5	A B C	12.9	9.6	5.25	6.71	2.4 - 2.6	2.5	3.9 4.3 4.1	3.8 3.6	0.375	0.11
	(4@3.9)5-12-F4.0-0-i-2.5-4-5	A B C D	12.8	9.6	5.25	6.54	2.5 - - 2.5	2.5	3.9 4.0 3.8 3.9	2.3 2.5 2.4	-	-
	(4@3.9)5-12-F4.0-2#3-i-2.5-4-5	A B C D	13.0	9.6	5.25	6.81	2.5 - - 2.5	2.5	4.1 4.1 3.9 4.1	2.5 2.4 2.5	0.375	0.11
	(4@3.9)5-12-F4.0-5#3-i-2.5-4-5	A B C D	13.3	9.5	5.25	-‡	2.5 - - 2.5	2.5	3.8 3.9 3.8 3.8	2.6 2.5 2.5	0.375	0.11
Group 15	11-5a-F3.8-0-i-2.5-3-17	A B	21.9	22.0	20	23.11	2.6 2.4	2.5	4.2 3.8	15.5	-	-
	11-5a-F3.8-2#3-i-2.5-3-17	A B	21.7	21.8	20	23.77	2.6 2.6	2.6	3.0 3.0	15.1	0.375	0.11
	11-5a-F3.8-6#3-i-2.5-3-17	A B	21.4	21.9	20	23.70	2.4 2.6	2.5	3.8 3.8	15.0	0.375	0.11

‡ d_{eff} was not calculated for specimen with bar yielding

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 14	5-12-F4.0-0-i-2.5-5-4	A B	-	-	-	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-12-F13.1-0-i-2.5-5-4	A B	-	-	-	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-12-F4.0-2#3-i-2.5-5-4	A B	4	3.5 (2.625)	0.22	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-12-F13.1-2#3-i-2.5-5-4	A B	4	3.5 (2.625)	0.22	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-12-F4.0-5#3-i-2.5-5-4	A B	10	1.75 (0.875)	0.66	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-12-F13.1-5#3-i-2.5-5-4	A B	10	1.75 (0.875)	0.66	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-12-F4.0-0-i-2.5-3-6	A B	-	-	-	0.375	3.5 (1.75)	0.22	2	0.62	A4
	5-12-F13.1-0-i-2.5-3-6	A B	-	-	-	0.375	3.5 (1.75)	0.22	2	0.62	A4
	(3@5.9)5-12-F4.0-0-i-2.5-4-5	A B C	-	-	-	0.375	3.5 (1.75)	0.22	3	0.93	A5
	(3@5.9)5-12-F4.0-2#3-i-2.5-4-5	A B C	4	3.5 (2.625)	0.22	0.375	3.5 (1.75)	0.22	3	0.93	A5
	(3@5.9)5-12-F4.0-5#3-i-2.5-4-5	A B C	10	1.75 (0.875)	0.66	0.375	3.5 (1.75)	0.22	3	0.93	A5
	(4@3.9)5-12-F4.0-0-i-2.5-4-5	A B C D	-	-	-	0.375	3.5 (1.75)	0.22	4	1.24	A5
	(4@3.9)5-12-F4.0-2#3-i-2.5-4-5	A B C D	4	3.5 (2.625)	0.22	0.375	3.5 (1.75)	0.22	4	1.24	A5
	(4@3.9)5-12-F4.0-5#3-i-2.5-4-5	A B C D	10	1.75 (0.875)	0.22	0.375	3.5 (1.75)	0.18	4	1.24	A5
Group 15	11-5a-F3.8-0-i-2.5-3-17	A B	-	-	-	0.5	4 (2)	1.20	2	3.12	A10
	11-5a-F3.8-2#3-i-2.5-3-17	A B	4	8 (6)	0.22	0.5	4 (2)	1.20	2	3.12	A10
	11-5a-F3.8-6#3-i-2.5-3-17	A B	12	4 (2)	0.66	0.5	4 (2)	1.20	2	3.12	A10

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 14	5-12-F4.0-0-i-2.5-5-4	A	CB	0.123	28.9	93.2	28.9	56.6	28.3	91.3
		B		0.055	27.7	89.4	27.7			
	5-12-F13.1-0-i-2.5-5-4	A	CB	0.179	32.6	105.2	32.5	62.7	31.4	101.3
		B		0.116	30.2	97.4	30.2			
	5-12-F4.0-2#3-i-2.5-5-4	A	CB	0.072	33.7	108.7	33.7	65.4	32.7	105.5
		B		0.015	31.7	102.3	31.7			
	5-12-F13.1-2#3-i-2.5-5-4	A	CB	0.136	34.4	111.0	34.4	72.5	36.3	117.1
		B		0.025	38.2	123.2	38.2			
	5-12-F4.0-5#3-i-2.5-5-4	A	CB	0.196	40.2	129.7	40.2	77.7	38.9	125.5
		B		0.308	37.5	121.0	37.5			
	5-12-F13.1-5#3-i-2.5-5-4	A	CB	0.172	40.8	131.6	40.8	80.6	40.3	130.0
		B		0.269	39.8	128.4	39.8			
	5-12-F4.0-0-i-2.5-3-6	A	SB	0.136	43.9	141.6	41.8	83.5	41.7	134.5
		B		0.226	41.6	134.2	41.6			
	5-12-F13.1-0-i-2.5-3-6	A	CB	0.081	44.7	144.2	44.5	88.3	44.2	142.6
		B		0.327	43.8	141.3	43.8			
	(3@5.9)5-12-F4.0-0-i-2.5-4-5	A	CB	-	27.1	87.4	27.0	84.1	28.0	90.4
		B		0.100	28.9	93.2	28.8			
		C		-	28.2	91.0	28.2			
	(3@5.9)5-12-F4.0-2#3-i-2.5-4-5	A	CB	0.169	34.5	111.3	34.5	105.4	35.1	113.3
		B		-	35.3	113.9	35.3			
		C		-	35.6	114.8	35.6			
	(3@5.9)5-12-F4.0-5#3-i-2.5-4-5	A	CB	0.266	42.5	137.1	42.3	115.9	38.6	124.6
		B		0.216	33.3	107.4	32.7			
		C		-	41.3	133.2	40.9			
	(4@3.9)5-12-F4.0-0-i-2.5-4-5	A	CB	0.099	28.3	91.3	28.3	-†	25.6†	82.7
		B		-	-†	-†	-			
		C		0.109	24.5	79.0	24.5			
		D		-	24.1	77.7	24.1			
	(4@3.9)5-12-F4.0-2#3-i-2.5-4-5	A	CB	0.123	33.5	108.1	33.3	-†	30.9†	99.7
		B		-	-†	-†	-			
		C		0.228	30.7	99.0	30.7			
		D		-	28.7	92.6	28.7			
	(4@3.9)5-12-F4.0-5#3-i-2.5-4-5	A	Y	-	48.9	157.7	48.0	-†	48.1†	155.2
		B		-	-†	-†	-			
		C		-	51.3	165.5	49.4			
		D		-	46.9	151.3	46.8			
Group 15	11-5a-F3.8-0-i-2.5-3-17	A	CB/FP	0.106	97.1	62.2	97.1	195.1	97.5	62.5
		B		0.043	98.0	62.8	98.0			
	11-5a-F3.8-2#3-i-2.5-3-17	A	SB/FP	0.337	117.7	75.4	117.7	236.5	118.2	75.8
		B		0.235	133.4	85.5	118.8			
	11-5a-F3.8-6#3-i-2.5-3-17	A	SB/FP	0.130	119.9	76.9	114.5	232.4	116.2	74.5
		B		0.041	118.0	75.6	118.0			

† Load on headed bar B was not recorded due to a malfunction of load cell; T taken as the average load of the other three bars.

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 15	11-5a-F3.8-0-i-2.5-3-12	A B	2.0	3.8A_b	12.19 11.81	12.00	3960	35	1.41	1.56
	11-5a-F3.8-2#3-i-2.5-3-12	A B	2.0	3.8A_b	11.81 12.19	12.00	3960	35	1.41	1.56
	11-5a-F3.8-6#3-i-2.5-3-12	A B	2.0	3.8A_b	12.13 12.06	12.09	3960	35	1.41	1.56
	11-5a-F8.6-0-i-2.5-3-12	A B	2.0	8.6A_b	12.13 12.13	12.13	3960	35	1.41	1.56
	11-5a-F8.6-6#3-i-2.5-3-12	A B	2.0	8.6A_b	12.69 12.44	12.56	4050	36	1.41	1.56
Group 16	8-8-F4.1-0-i-2.5-3-10-DB	A B	2.0	4.1A_b	9.88 9.88	9.88	7410	49	1	0.79
	8-8-F9.1-0-i-2.5-3-10-DB	A B	2.0	9.1A_b	9.88 9.75	9.81	7410	49	1	0.79
	8-8-F9.1-5#3-i-2.5-3-10-DB	A B	2.0	9.1A_b	9.63 9.63	9.63	7410	49	1	0.79
	8-5-F4.1-0-i-2.5-3-10-DB	A B	2.0	4.1A_b	9.88 9.88	9.88	4880	19	1	0.79
	8-5-F9.1-0-i-2.5-3-10-DB	A B	2.0	9.1A_b	9.63 9.88	9.75	4880	19	1	0.79
	8-5-F4.1-3#4-i-2.5-3-10-DB	A B	2.0	4.1A_b	10.00 10.25	10.13	4880	19	1	0.79
	8-5-F9.1-3#4-i-2.5-3-10-DB	A B	2.0	9.1A_b	9.75 9.75	9.75	4880	20	1	0.79
	8-5-F4.1-5#3-i-2.5-3-10-DB	A B	2.0	4.1A_b	10.25 10.13	10.19	4880	20	1	0.79
	8-5-F9.1-5#3-i-2.5-3-10-DB	A B	2.0	9.1A_b	10.00 9.88	9.94	4880	20	1	0.79
Group 17	11-8-F3.8-0-i-2.5-3-14.5	A B	2.0	3.8A_b	14.50 14.50	14.50	8660	19	1.41	1.56
	11-8-F3.8-2#3-i-2.5-3-14.5	A B	2.0	3.8A_b	14.63 14.75	14.69	8660	19	1.41	1.56
	11-8-F3.8-6#3-i-2.5-3-14.5	A B	2.0	3.8A_b	14.88 14.50	14.69	8660	19	1.41	1.56
	(3@5.35)11-8-F3.8-0-i-2.5-3-14.5	A B C	2.0	3.8A_b	14.38 14.75 14.75	14.63	8720	20	1.41	1.56
	(3@5.35)11-8-F3.8-2#3-i-2.5-3-14.5	A B C	2.0	3.8A_b	14.50 14.63 14.50	14.54	8720	20	1.41	1.56
	(3@5.35)11-8-F3.8-6#3-i-2.5-3-14.5	A B C	2.0	3.8A_b	15.13 14.88 14.75	14.92	8720	20	1.41	1.56

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 15	11-5a-F3.8-0-i-2.5-3-12	A B	21.7	16.5	20	21.84	2.6 2.8	2.7	2.9 3.3	14.9	-	-
	11-5a-F3.8-2#3-i-2.5-3-12	A B	21.4	17.1	20	22.18	2.4 2.4	2.4	3.9 3.5	15.3	0.375	0.11
	11-5a-F3.8-6#3-i-2.5-3-12	A B	21.6	17.0	20	22.53	2.8 2.5	2.7	3.5 3.6	14.9	0.375	0.11
	11-5a-F8.6-0-i-2.5-3-12	A B	21.7	16.8	20	22.07	2.8 2.5	2.6	3.3 3.3	15.0	-	-
	11-5a-F8.6-6#3-i-2.5-3-12	A B	22.0	17.3	20	22.53	2.8 2.7	2.7	3.3 3.5	15.2	0.375	0.11
Group 16	8-8-F4.1-0-i-2.5-3-10-DB	A B	17.1	14.3	20	21.38	2.5 2.6	2.6	3.4 3.4	11.0	-	-
	8-8-F9.1-0-i-2.5-3-10-DB	A B	17.3	14.2	20	21.42	2.6 2.6	2.6	3.3 3.4	11.0	-	-
	8-8-F9.1-5#3-i-2.5-3-10-DB	A B	17.4	14.2	20	21.88	2.5 2.8	2.6	3.6 3.6	11.1	0.375	0.11
	8-5-F4.1-0-i-2.5-3-10-DB	A B	17.4	14.1	20	21.43	2.5 2.6	2.6	3.3 3.3	11.3	-	-
	8-5-F9.1-0-i-2.5-3-10-DB	A B	17.5	14.3	20	21.56	2.6 2.6	2.6	3.6 3.4	11.3	-	-
	8-5-F4.1-3#4-i-2.5-3-10-DB	A B	17.3	14.1	20	22.27	2.5 2.5	2.5	3.1 2.9	11.3	0.5	0.2
	8-5-F9.1-3#4-i-2.5-3-10-DB	A B	17.3	14.4	20	22.31	2.6 2.6	2.6	3.6 3.6	11.0	0.5	0.2
	8-5-F4.1-5#3-i-2.5-3-10-DB	A B	17.5	14.3	20	22.47	2.6 2.8	2.7	3.1 3.2	11.1	0.375	0.11
	8-5-F9.1-5#3-i-2.5-3-10-DB	A B	17.3	14.2	20	22.48	2.6 2.6	2.6	3.2 3.3	11.0	0.375	0.11
Group 17	11-8-F3.8-0-i-2.5-3-14.5	A B	21.8	19.3	20	21.54	2.8 2.5	2.6	3.4 3.4	15.1	-	-
	11-8-F3.8-2#3-i-2.5-3-14.5	A B	21.8	19.3	20	21.72	2.5 2.6	2.6	3.3 3.1	15.3	0.375	0.11
	11-8-F3.8-6#3-i-2.5-3-14.5	A B	21.7	19.4	20	22.19	2.4 2.5	2.4	3.2 3.6	15.4	0.375	0.11
	(3@5.35)11-8-F3.8-0-i-2.5-3-14.5	A B C	22.0	19.3	20	21.53	2.8 - 2.8	2.8	3.6 3.2 3.2	7.5 7.6	-	-
	(3@5.35)11-8-F3.8-2#3-i-2.5-3-14.5	A B C	21.8	19.2	20	22.10	2.5 - 2.6	2.6	3.3 3.2 3.3	7.5 7.8	0.375	0.11
	(3@5.35)11-8-F3.8-6#3-i-2.5-3-14.5	A B C	22.2	19.6	20	22.42	2.8 - 2.8	2.8	3.1 3.4 3.5	7.6 7.6	0.375	0.11

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 15	11-5a-F3.8-0-i-2.5-3-12	A B	-	-	-	0.5	5 (2.5)	1.20	2	3.12	A11
	11-5a-F3.8-2#3-i-2.5-3-12	A B	4	8 (6)	0.22	0.5	5 (2.5)	1.20	2	3.12	A11
	11-5a-F3.8-6#3-i-2.5-3-12	A B	12	4 (2)	0.66	0.5	5 (2.5)	1.20	2	3.12	A11
	11-5a- F8.6-0-i-2.5-3-12	A B	-	-	-	0.5	5 (2.5)	1.20	2	3.12	A11
	11-5a-F8.6-6#3-i-2.5-3-12	A B	12	4 (2)	0.66	0.5	5 (2.5)	1.20	2	3.12	A11
Group 16	8-8-F4.1-0-i-2.5-3-10-DB	A B	-	-	-	0.5	5 (2.5)	0.80	2	1.58	A12
	8-8-F9.1-0-i-2.5-3-10-DB	A B	-	-	-	0.5	5 (2.5)	0.80	2	1.58	A12
	8-8-F9.1-5#3-i-2.5-3-10-DB	A B	10	5 (2.5)	0.44	0.5	5 (2.5)	0.80	2	1.58	A12
	8-5-F4.1-0-i-2.5-3-10-DB	A B	-	-	-	0.5	5 (2.5)	0.80	2	1.58	A12
	8-5-F9.1-0-i-2.5-3-10-DB	A B	-	-	-	0.5	5 (2.5)	0.80	2	1.58	A12
	8-5-F4.1-3#4-i-2.5-3-10-DB	A B	6	7.5 (6)	0.40	0.5	5 (2.5)	0.80	2	1.58	A12
	8-5-F9.1-3#4-i-2.5-3-10-DB	A B	6	7.5 (6)	0.40	0.5	5 (2.5)	0.80	2	1.58	A12
	8-5-F4.1-5#3-i-2.5-3-10-DB	A B	10	5 (2.5)	0.44	0.5	5 (2.5)	0.80	2	1.58	A12
	8-5-F9.1-5#3-i-2.5-3-10-DB	A B	10	5 (2.5)	0.44	0.5	5 (2.5)	0.80	2	1.58	A12
Group 17	11-8-F3.8-0-i-2.5-3-14.5	A B	-	-	-	0.5	5 (2.5)	1.20	2	3.12	A12
	11-8-F3.8-2#3-i-2.5-3-14.5	A B	4	8 (6)	0.22	0.5	5 (2.5)	1.20	2	3.12	A12
	11-8-F3.8-6#3-i-2.5-3-14.5	A B	12	4 (2)	0.66	0.5	5 (2.5)	1.20	2	3.12	A12
	(3@5.35)11-8-F3.8-0-i-2.5-3-14.5	A B C	-	-	-	0.5	5 (2.5)	1.20	3	4.68	A13
	(3@5.35)11-8-F3.8-2#3-i-2.5-3-14.5	A B C	4	8 (6)	0.22	0.5	5 (2.5)	1.20	3	4.68	A14
	(3@5.35)11-8-F3.8-6#3-i-2.5-3-14.5	A B C	12	4 (2)	0.66	0.5	5 (2.5)	1.20	3	4.68	A14

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 15	11-5a-F3.8-0-i-2.5-3-12	A	CB	0.025	54.2	34.7	54.2	113.7	56.8	36.4
		B		0.006	59.5	38.1	59.5			
	11-5a-F3.8-2#3-i-2.5-3-12	A	CB	0.231	67.2	43.1	67.2	134.6	67.3	43.1
		B		0.007	67.4	43.2	67.4			
	11-5a-F3.8-6#3-i-2.5-3-12	A	CB/FP	0.007	77.4	49.6	77.4	156.0	78.0	50.0
		B		0.429	82.3	52.8	78.6			
	11-5a-F8.6-0-i-2.5-3-12	A	CB	0.202	63.7	40.8	63.7	127.7	63.8	40.9
		B		0.145	75.4	48.3	64.0			
	11-5a-F8.6-6#3-i-2.5-3-12	A	CB	0.237	78.3	50.2	78.3	158.4	79.2	50.8
		B		0.250	80.2	51.4	80.2			
Group 16	8-8-F4.1-0-i-2.5-3-10-DB	A	CB	0.129	49.9	63.2	49.9	100.3	50.2	63.5
		B		0.065	50.5	63.9	50.5			
	8-8-F9.1-0-i-2.5-3-10-DB	A	CB	0.010	47.4	60.0	47.4	103.6	51.8	65.6
		B		0.036	56.2	71.1	56.2			
	8-8-F9.1-5#3-i-2.5-3-10-DB	A	CB	0.012	65.5	82.9	65.5	136.5	68.2	86.3
		B		0.102	71.0	89.9	71.0			
	8-5-F4.1-0-i-2.5-3-10-DB	A	CB/FP	0.188	37.4	47.3	37.4	81.3	40.6	51.4
		B		0.322	44.4	56.2	43.9			
	8-5-F9.1-0-i-2.5-3-10-DB	A	CB	0.061	42.6	53.9	39.0	88.7	44.4	56.2
		B		0.008	49.7	62.9	49.7			
	8-5-F4.1-3#4-i-2.5-3-10-DB	A	CB	0.081	60.6	76.7	60.6	129.2	64.6	81.8
		B		0.180	68.7	87.0	68.7			
	8-5-F9.1-3#4-i-2.5-3-10-DB	A	CB	0.017	62.4	79.0	62.4	131.5	65.8	83.3
		B		0.258	69.1	87.5	69.1			
	8-5-F4.1-5#3-i-2.5-3-10-DB	A	CB	0.019	63.2	80.0	63.2	140.4	70.2	88.9
		B		0.120	77.2	97.7	77.2			
	8-5-F9.1-5#3-i-2.5-3-10-DB	A	CB	0.120	66.8	84.6	66.8	141.0	70.5	89.2
		B		0.248	74.2	93.9	74.2			
Group 17	11-8-F3.8-0-i-2.5-3-14.5	A	CB	0.123	79.4	50.9	79.4	158.1	79.1	50.7
		B		0.008	78.7	50.4	78.7			
	11-8-F3.8-2#3-i-2.5-3-14.5	A	CB	0.591	87.8	56.3	87.8	176.9	88.4	56.7
		B		0.008	89.1	57.1	89.1			
	11-8-F3.8-6#3-i-2.5-3-14.5	A	CB	0.140	112.4	72.1	112.4	225.3	112.7	72.2
		B		0.178	112.9	72.4	112.9			
	(3@5.35)11-8-F3.8-0-i-2.5-3-14.5	A	CB	-	51.9	33.3	51.9	158.7	52.9	33.9
		B		0.040	54.9	35.2	54.9			
		C		-	51.9	33.3	51.9			
	(3@5.35)11-8-F3.8-2#3-i-2.5-3-14.5	A	CB	-	74.0	47.4	74.0	217.7	72.6	46.5
		B		0.260	72.1	46.2	72.1			
		C		-	71.6	45.9	71.6			
	(3@5.35)11-8-F3.8-6#3-i-2.5-3-14.5	A	CB	-	93.2	59.7	93.2	251.0	83.7	53.7
		B		0.211	85.3	54.7	85.3			
		C		0.292	72.4	46.4	72.4			

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 17	8-8-O12.9-0-i-2.5-3-9.5	A B	1.0	12.9A_b	9.75 9.63	9.69	8800	21	1	0.79
	8-8-S14.9-0-i-2.5-3-8.25	A B	1.0	14.9A_b	8.25 8.25	8.25	8800	21	1	0.79
	8-8-O12.9-5#3-i-2.5-3-9.5	A B	1.0	12.9A_b	9.50 9.25	9.38	8800	21	1	0.79
	8-8-S14.9-5#3-i-2.5-3-8.25	A B	1.0	14.9A_b	8.25 8.25	8.25	8800	21	1	0.79
Group 18	11-5-F3.8-0-i-2.5-3-12	A B	2.0	3.8A_b	12.13 12.13	12.13	5760	6	1.41	1.56
	11-5-F3.8-6#3-i-2.5-3-12	A B	2.0	3.8A_b	12.50 12.50	12.50	5760	6	1.41	1.56
	11-5-F3.8-0-i-2.5-3-17	A B	2.0	3.8A_b	17.50 17.00	17.25	5760	6	1.41	1.56
	11-5-F3.8-6#3-i-2.5-3-17	A B	2.0	3.8A_b	16.88 17.00	16.94	5970	7	1.41	1.56
	11-5-F8.6-0-i-2.5-3-14.5	A B	2.0	8.6A_b	14.50 14.50	14.50	5970	7	1.41	1.56
	11-5-F8.6-6#3-i-2.5-3-14.5	A B	2.0	8.6A_b	14.50 14.75	14.63	5970	7	1.41	1.56
	(3@5.35)11-5-F8.6-0-i-2.5-3-14.5	A B C	2.0	8.6A_b	14.38 15.25 14.50	14.71	6240	8	1.41	1.56
	(3@5.35)11-5-F8.6-6#3-i-2.5-3-14.5	A B C	2.0	8.6A_b	14.75 14.50 14.38	14.54	6240	8	1.41	1.56
Group 19	11-12-O4.5-0-i-2.5-3-16.75	A B	1.3	4.5A_b	17.13 17.13	17.13	10860	36	1.41	1.56
	11-12-S5.5-0-i-2.5-3-16.75	A B	1.5	5.5A_b	16.75 17.13	16.94	10120	37	1.41	1.56
	11-12-O4.5-6#3-i-2.5-3-16.75	A B	1.3	4.5A_b	16.75 16.88	16.81	10860	37	1.41	1.56
	11-12-S5.5-6#3-i-2.5-3-16.75	A B	1.5	5.5A_b	16.63 17.00	16.81	10120	38	1.41	1.56
	(3@5.35)11-12-O4.5-0-i-2.5-3-16.75	A B C	1.3	4.5A_b	16.88 17.13 16.75	16.92	10860	36	1.41	1.56
	(3@5.35)11-12-S5.5-0-i-2.5-3-16.75	A B C	1.5	5.5A_b	16.88 17.00 16.88	16.92	10120	38	1.41	1.56
	(3@5.35)11-12-O4.5-6#3-i-2.5-3-16.75	A B C	1.3	4.5A_b	16.88 17.13 17.00	17.00	10860	37	1.41	1.56
	(3@5.35)11-12-S5.5-6#3-i-2.5-3-16.75	A B C	1.5	5.5A_b	16.75 17.00 16.50	16.75	10120	38	1.41	1.56

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 17	8-8-O12.9-0-i-2.5-3-9.5	A B	16.9	14.3	10.25	12.31	2.5 2.5	2.5	2.9 3.0	10.9	-	-
	8-8-S14.9-0-i-2.5-3-8.25	A B	17.3	14.3	10.25	11.97	2.6 2.6	2.6	3.3 3.3	11.0	-	-
	8-8-O12.9-5#3-i-2.5-3-9.5	A B	17.1	14.2	10.25	12.27	2.5 2.6	2.6	3.1 3.3	11.0	0.375	0.11
	8-8-S14.9-5#3-i-2.5-3-8.25	A B	17.3	14.1	10.25	12.36	2.8 2.5	2.6	3.1 3.1	11.0	0.375	0.11
Group 18	11-5-F3.8-0-i-2.5-3-12	A B	21.7	17.0	20	21.66	2.8 2.5	2.6	3.5 3.5	15.0	-	-
	11-5-F3.8-6#3-i-2.5-3-12	A B	21.8	16.9	20	22.20	2.6 2.8	2.7	3.1 3.1	15.0	0.375	0.11
	11-5-F3.8-0-i-2.5-3-17	A B	21.9	21.9	20	23.31	2.5 3.0	2.8	3.0 3.5	15.0	-	-
	11-5-F3.8-6#3-i-2.5-3-17	A B	21.5	22.0	20	23.70	2.6 2.5	2.6	3.8 3.6	15.0	0.375	0.11
	11-5-F8.6-0-i-2.5-3-14.5	A B	21.7	19.1	20	22.02	2.5 2.6	2.6	3.3 3.3	15.1	-	-
	11-5-F8.6-6#3-i-2.5-3-14.5	A B	21.5	19.5	20	22.74	2.6 2.6	2.6	3.6 3.4	14.9	0.375	0.11
	(3@5.35)11-5-F8.6-0-i-2.5-3-14.5	A B C	21.3	19.2	20	22.32	2.6 - 2.5	2.6	3.4 2.6 3.3	7.3 7.5	-	-
	(3@5.35)11-5-F8.6-6#3-i-2.5-3-14.5	A B C	21.4	19.1	20	22.70	2.5 - 2.8	2.6	3.0 3.3 3.4	7.4 7.4	0.375	0.11
Group 19	11-12-O4.5-0-i-2.5-3-16.75	A B	21.9	23.1	20	22.63	2.8 2.8	2.8	3.9 3.9	15.0	-	-
	11-12-S5.5-0-i-2.5-3-16.75	A B	22.3	23.1	20	22.93	2.8 2.9	2.8	3.6 3.2	15.3	-	-
	11-12-O4.5-6#3-i-2.5-3-16.75	A B	21.7	23.1	20	23.12	2.5 2.8	2.6	4.3 4.1	15.0	0.375	0.11
	11-12-S5.5-6#3-i-2.5-3-16.75	A B	22.4	22.7	20	23.28	2.6 3.0	2.8	3.3 2.9	15.4	0.375	0.11
	(3@5.35)11-12-O4.5-0-i-2.5-3-16.75	A B C	21.8	22.9	20	22.48	3.0 - 2.5	2.8	3.9 3.6 4.0	7.5 7.4	-	-
	(3@5.35)11-12-S5.5-0-i-2.5-3-16.75	A B C	21.9	23.1	20	22.72	2.8 - 2.8	2.8	3.5 3.4 3.5	7.5 7.5	-	-
	(3@5.35)11-12-O4.5-6#3-i-2.5-3-16.75	A B C	21.8	22.9	20	23.16	2.5 - 2.8	2.6	3.9 3.7 3.8	7.5 7.6	0.375	0.11
	(3@5.35)11-12-S5.5-6#3-i-2.5-3-16.75	A B C	21.9	22.8	20	23.84	2.6 - 3.0	2.8	3.3 3.0 3.5	7.4 7.5	0.375	0.11

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 17	8-8-O12.9-0-i-2.5-3-9.5	A B	-	-	-	0.5	4.5 (2.25)	0.80	2	1.58	A6
	8-8-S14.9-0-i-2.5-3-8.25	A B	-	-	-	0.5	4.5 (2.25)	0.80	2	1.58	A6
	8-8-O12.9-5#3-i-2.5-3-9.5	A B	10	3 (1.5)	0.66	0.5	4.5 (2.25)	0.80	2	1.58	A6
	8-8-S14.9-5#3-i-2.5-3-8.25	A B	10	3 (1.5)	0.66	0.5	4.5 (2.25)	0.80	2	1.58	A6
Group 18	11-5-F3.8-0-i-2.5-3-12	A B	-	-	-	0.5	5 (2.5)	1.20	2	3.12	A6
	11-5-F3.8-6#3-i-2.5-3-12	A B	12	4 (2)	0.66	0.5	5 (2.5)	1.20	2	3.12	A12
	11-5-F3.8-0-i-2.5-3-17	A B	-	-	-	0.5	6 (3)	0.80	2	3.12	A7
	11-5-F3.8-6#3-i-2.5-3-17	A B	12	4 (2)	0.66	0.5	6 (3)	0.80	2	3.12	A7
	11-5-F8.6-0-i-2.5-3-14.5	A B	-	-	-	0.5	5 (2.5)	1.20	2	3.12	A12
	11-5-F8.6-6#3-i-2.5-3-14.5	A B	12	4 (2)	0.66	0.5	5 (2.5)	1.20	2	3.12	A12
	(3@5.35)11-5-F8.6-0-i-2.5-3-14.5	A B C	-	-	-	0.5	5 (2.5)	1.20	3	4.68	A15
	(3@5.35)11-5-F8.6-6#3-i-2.5-3-14.5	A B C	12	4 (2)	0.66	0.5	4.5 (2.25)	1.20	3	4.68	A15
Group 19	11-12-O4.5-0-i-2.5-3-16.75	A B	-	-	-	0.5	4 (2)	1.20	2	3.12	A16
	11-12-S5.5-0-i-2.5-3-16.75	A B	-	-	-	0.5	4 (2)	1.20	2	3.12	A16
	11-12-O4.5-6#3-i-2.5-3-16.75	A B	12	4 (2)	0.66	0.5	4 (2)	1.20	2	3.12	A16
	11-12-S5.5-6#3-i-2.5-3-16.75	A B	12	4 (2)	0.66	0.5	4 (2)	1.20	2	3.12	A16
	(3@5.35)11-12-O4.5-0-i-2.5-3-16.75	A B C	-	-	-	0.5	4 (2)	1.20	3	4.68	A16
	(3@5.35)11-12-S5.5-0-i-2.5-3-16.75	A B C	-	-	-	0.5	4 (2)	1.20	3	4.68	A16
	(3@5.35)11-12-O4.5-6#3-i-2.5-3-16.75	A B C	12	4 (2)	0.66	0.5	4 (2)	1.20	3	4.68	A16
	(3@5.35)11-12-S5.5-6#3-i-2.5-3-16.75	A B C	12	4 (2)	0.66	0.5	4 (2)	1.20	3	4.68	A16

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip	T_{max}	$f_{su,max}$	T_{ind}	T_{total}	T	f_{su}
				in.	kips	ksi	kips	kips	kips	ksi
Group 17	8-8-O12.9-0-i-2.5-3-9.5	A	CB	-	85.5	108.2	85.5	170.5	85.2	107.8
		B		-	84.9	107.5	84.9			
	8-8-S14.9-0-i-2.5-3-8.25	A	CB	0.010	70.8	89.6	70.8	141.8	70.9	89.7
		B		0.187	71.0	89.9	71.0			
	8-8-O12.9-5#3-i-2.5-3-9.5	A	CB	0.237	84.4	106.8	84.4	166.9	83.5	105.7
		B		0.198	82.5	104.4	82.5			
	8-8-S14.9-5#3-i-2.5-3-8.25	A	CB	0.197	87.2	110.4	87.2	174.0	87.0	110.1
		B		0.022	86.8	109.9	86.8			
Group 18	11-5-F3.8-0-i-2.5-3-12	A	CB	0.140	68.7	44.0	68.7	132.9	66.5	42.6
		B		0.262	64.3	41.2	64.3			
	11-5-F3.8-6#3-i-2.5-3-12	A	CB	0.041	88.2	56.5	88.2	176.5	88.3	56.6
		B		0.008	88.3	56.6	88.3			
	11-5-F3.8-0-i-2.5-3-17	A	CB/FP	0.115	132.6	85.0	132.6	265.5	132.7	85.1
		B		0.015	132.9	85.2	132.9			
	11-5-F3.8-6#3-i-2.5-3-17	A	CB	0.157	154.9	99.3	154.9	303.7	151.9	97.4
		B		0.051	148.9	95.4	148.9			
	11-5-F8.6-0-i-2.5-3-14.5	A	CB	0.005	83.6	53.6	83.6	165.7	82.8	53.1
		B		0.783	82.1	52.6	82.1			
	11-5-F8.6-6#3-i-2.5-3-14.5	A	CB	0.144	113.9	73.0	113.9	224.6	112.3	72.0
		B		0.010	110.7	71.0	110.7			
	(3@5.35)11-5-F8.6-0-i-2.5-3-14.5	A	CB	-	66.5	42.6	66.5	195.4	65.1	41.7
		B		0.013	61.7	39.6	61.7			
		C		0.068	67.1	43.0	67.1			
	(3@5.35)11-5-F8.6-6#3-i-2.5-3-14.5	A	CB	-	68.8	44.1	68.8	226.9	75.6	48.5
		B		0.287	83.3	53.4	83.2			
		C		0.016	74.9	48.0	74.9			
Group 19	11-12-O4.5-0-i-2.5-3-16.75	A	CB	0.032	168.4	107.9	168.3	339.3	169.6	108.7
		B		0.029	171.0	109.6	171.0			
	11-12-S5.5-0-i-2.5-3-16.75	A	CB	0.091	179.1	114.8	179.1	351.9	175.9	112.8
		B		0.215	172.7	110.7	172.7			
	11-12-O4.5-6#3-i-2.5-3-16.75	A	SB/FP	0.024	202.5	129.8	202.5	403.0	201.5	129.2
		B		0.022	200.7‡	128.7‡	200.5			
	11-12-S5.5-6#3-i-2.5-3-16.75	A	CB	0.028	206.1	132.1	206.1	394.8	197.4	126.5
		B		0.025	188.7	121.0	188.7			
	(3@5.35)11-12-O4.5-0-i-2.5-3-16.75	A	CB	-	109.3	70.1	107.6	320.4	106.8	68.5
		B		0.003	114.1	73.1	114.1			
		C		0.003	98.7	63.3	98.7			
	(3@5.35)11-12-S5.5-0-i-2.5-3-16.75	A	CB	-	117.1	75.1	117.1	327.0	109.0	69.9
		B		-	93.8	60.1	93.8			
		C		-	116.1	74.4	116.1			
	(3@5.35)11-12-O4.5-6#3-i-2.5-3-16.75	A	CB	-	131.7	84.4	131.7	407.4	135.8	87.1
		B		0.213	131.8	84.5	131.8			
		C		0.145	143.9	92.2	143.9			
	(3@5.35)11-12-S5.5-6#3-i-2.5-3-16.75	A	CB	-	155.9	99.9	155.9	461.3	153.8	98.6
		B		0.095	154.9	99.3	154.9			
		C		-	150.6	96.5	150.6			

‡ No anchorage failure on the bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	c_o in.	A_{brg}	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f_{cm} psi	Age days	d_b in.	A_b in.^{2}
Group 20	11-5-O4.5-0-i-2.5-3-19.25	A B	1.3	$4.5A_b$	19.63 19.25	19.44	5430	12	1.41	1.56
	11-5-S5.5-0-i-2.5-3-19.25	A B	1.5	$5.5A_b$	19.38 19.38	19.38	6320	11	1.41	1.56
	11-5-O4.5-6#3-i-2.5-3-19.25	A B	1.3	$4.5A_b$	19.50 19.75	19.63	5430	12	1.41	1.56
	11-5-S5.5-6#3-i-2.5-3-19.25	A B	1.5	$5.5A_b$	19.13 19.13	19.13	6320	13	1.41	1.56
	(3@5.35)11-5-O4.5-0-i-2.5-3-19.25	A B C	1.3	$4.5A_b$	19.50 19.63 19.38	19.50	5430	12	1.41	1.56
	(3@5.35)11-5-S5.5-0-i-2.5-3-19.25	A B C	1.5	$5.5A_b$	19.25 19.38 19.25	19.29	6320	11	1.41	1.56
	(3@5.35)11-5-O4.5-6#3-i-2.5-3-19.25	A B C	1.3	$4.5A_b$	19.38 19.63 19.13	19.38	5430	13	1.41	1.56
	(3@5.35)11-5-S5.5-6#3-i-2.5-3-19.25	A B C	1.5	$5.5A_b$	19.00 19.38 19.38	19.25	6320	13	1.41	1.56

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	b in.	h in.	h_{cl} in.	d_{eff} in.	c_{so} in.	$c_{so,avg}$ in.	c_{bc} in.	c_{ch} in.	d_{tr} in.	$A_{tr,l}$ in.^{2}
Group 20	11-5-O4.5-0-i-2.5-3-19.25	A B	21.9	25.6	20	24.09	2.6 2.8	2.7	3.9 4.3	15.1	-	-
	11-5-S5.5-0-i-2.5-3-19.25	A B	22.0	25.4	20	24.17	2.5 3.0	2.8	3.3 3.3	15.1	-	-
	11-5-O4.5-6#3-i-2.5-3-19.25	A B	21.7	25.6	20	24.70	2.5 2.8	2.6	3.9 3.7	15.0	0.375	0.11
	11-5-S5.5-6#3-i-2.5-3-19.25	A B	22.2	25.3	20	24.47	2.8 2.8	2.8	3.4 3.4	15.3	0.375	0.11
	(3@5.35)11-5-O4.5-0-i-2.5-3-19.25	A B C	22.0	25.4	20	25.00	2.8 - 2.8	2.8	3.8 3.6 3.9	7.6 7.5	-	-
	(3@5.35)11-5-S5.5-0-i-2.5-3-19.25	A B C	21.9	25.5	20	24.86	2.8 - 2.8	2.8	3.5 3.4 3.5	7.5 7.5	-	-
	(3@5.35)11-5-O4.5-6#3-i-2.5-3-19.25	A B C	21.8	25.4	20	25.50	2.5 - 2.6	2.6	3.9 3.6 4.1	7.6 7.6	0.375	0.11
	(3@5.35)11-5-S5.5-6#3-i-2.5-3-19.25	A B C	21.8	25.4	20	25.41	2.6 - 2.8	2.7	3.6 3.3 3.3	7.3 7.8	0.375	0.11

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	N	s_{tr}* in.	A_{tt} in.^{2}	d_{tro} in.	s_{tro}* in.	A_{ab} in.^{2}	n	A_{hs} in.^{2}	Long. Reinf. Layout
Group 20	11-5-O4.5-0-i-2.5-3-19.25	A B	-	-	-	0.5	4 (2)	1.20	2	3.12	A16
	11-5-S5.5-0-i-2.5-3-19.25	A B	-	-	-	0.5	4 (2)	1.20	2	3.12	A16
	11-5-O4.5-6#3-i-2.5-3-19.25	A B	12	4 (2)	0.66	0.5	4 (2)	1.20	2	3.12	A16
	11-5-S5.5-6#3-i-2.5-3-19.25	A B	12	4 (2)	0.66	0.5	4 (2)	1.20	2	3.12	A16
	(3@5.35)11-5-O4.5-0-i-2.5-3-19.25	A B C	-	-	-	0.5	4 (2)	1.20	3	4.68	A16
	(3@5.35)11-5-S5.5-0-i-2.5-3-19.25	A B C	-	-	-	0.5	4 (2)	1.20	3	4.68	A16
	(3@5.35)11-5-O4.5-6#3-i-2.5-3-19.25	A B C	12	4 (2)	0.66	0.5	4 (2)	1.20	3	4.68	A16
	(3@5.35)11-5-S5.5-6#3-i-2.5-3-19.25	A B C	12	4 (2)	0.66	0.5	4 (2)	1.20	3	4.68	A16

* Value in parenthesis is the spacing between the first hoop and the center of the headed bar

Table A.3 Cont. Comprehensive test results and data for beam-column joint specimens

	Specimen	Head	Failure Type	Lead (Head) Slip in.	T_{max} kips	$f_{su,max}$ ksi	T_{ind} kips	T_{total} kips	T kips	f_{su} ksi
Group 20	11-5-O4.5-0-i-2.5-3-19.25	A B	SB/FP	0.021 0.128	161.4 154.4	103.5 99.0	161.4 154.3	315.7	157.9	101.2
	11-5-S5.5-0-i-2.5-3-19.25	A B	SB/FP	0.117 0.095	176.9 176.8‡	113.4 113.3‡	176.9 176.7	353.6	176.8	113.3
	11-5-O4.5-6#3-i-2.5-3-19.25	A B	SB/FP	0.012 0.036	180.4‡ 182.6	115.6‡ 117.1	180.3 182.6	362.9	181.4	116.3
	11-5-S5.5-6#3-i-2.5-3-19.25	A B	SB/FP	0.316 0.147	191.5‡ 187.7	122.8‡ 120.3	191.5 187.7	379.2	189.6	121.5
	(3@5.35)11-5-O4.5-0-i-2.5-3-19.25	A B C	CB	0.001 - -	132.5 127.5 126.0	84.9 81.7 80.8	132.5 127.5 126.0	386.0	128.7	82.5
	(3@5.35)11-5-S5.5-0-i-2.5-3-19.25	A B C	CB/BS	- 0.321 0.105	137.3 140.5 134.9	88.0 90.1 86.5	137.3 140.4 134.5	412.2	137.4	88.1
	(3@5.35)11-5-O4.5-6#3-i-2.5-3-19.25	A B C	CB	- - 0.042	137.4 137.1 150.7	88.1 87.9 96.6	137.4 137.1 150.7	425.1	141.7	90.8
	(3@5.35)11-5-S5.5-6#3-i-2.5-3-19.25	A B C	CB	- - 0.020	151.6 157.4 149.5	97.2 100.9 95.8	151.6 157.4 149.5	458.6	152.9	98.0

‡ No anchorage failure on the bar